Mined Rock and Overburden Piles

Methods of Monitoring

Interim Report

March, 1992

British Columbia
Mine Waste
Rock Pile
Research
Committee

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Report on

Methods of Monitoring Waste Dumps Located in Mountainous Terrain

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FOREWORD

Mine waste rock and overburden dumps are massive structures. Mountain top coal mines in British Columbia are constructing the largest man-made structures on the face of the earth. These immense waste dumps are often up to 400 meters high, contain in excess of one billion cubic meters of material, and often form mid-valley fills or rock drains. Instability of the structures has caused increased concern by mine operators and government regulators because of risk to the safety of personnel, equipment and infrastructure, and their impact on the environment.

In mid-1990 representatives of industry, CANMET, and the Ministries of Environment, and Energy, Mines and Petroleum Resources formed the Mine Waste Rock Pile Research Committee to foster research work and ensure a common understanding of these waste dumps.

The Interim Guidelines, published in May 1991, were the first two documents in a series undertaken by the committee. Three Interim Reports (Methods of Monitoring, Failure Runout Characteristics, Volumes I and II, and Review and Evaluation of Failures) continue the series of studies directed at improving our understanding of behaviour and developing a consistent database for waste dumps. Prominent geotechnical consultants and industry representatives have contributed their expertise to the studies.

The interim studies are being widely distributed by the Ministry of Energy, Mines And Petroleum Resources in the hope that all concerned with mine dumps will find them useful in establishing dumps that are stable, safe, and economically feasible. I anticipate that the studies will be distilled in the next year to develop a standard for investigation, design, operation, and monitoring of mine dumps.

In April 1992 the committee is sponsoring a series of workshops to introduce all of the studies to key industry personnel.

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Resource Management Branch

March 6, 1992

RESEARCH PROJECTS COMPLETED BY THE COMMITTEE

Investigation and Design Manual	(1991)
Operating and Monitoring Manual	(1991)
Methods of Monitoring	(1992)
Failure Runout Characteristics - Volumes I and II	(1992)
Review and Evaluation of Failures	(1992)

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1.0 SUMMARY AND REPORT ORGANIZATION

1.1 Summary

This report summarizes available and prospective instrumentation for application to dump monitoring with emphasis to mountain dumps. The current situation is that most dumps are monitored using wireline extensometers and visual methods; some also use EDM monitoring methods and a very few use piezometric measuring methods. There is also an increasing trend in dump failure rates, particularly for high coal mine dumps.

The state of the presently used instrumentation is not completely satisfactory, particularly with respect to monitoring of Class III and IV dumps (defined in B.C. Design Guidelines, Piteau and Associates, 1991). The following potential problems, among others, are identified in this report:

a) The wireline extensometer which is used to control dumping with respect to movement rates may read from 0 to 100% of the actual movement rate for different situations resulting in uncertain control using this type of instrument. As with any instrumentation system, care in the deployment and interpretation of the results is required.

b) Movement rates are often controlled by piezometric pressures for deep seated failure modes and there are very few dumps with installed piezometers.

c) The wireline extensometer provides short-term rate movement data only and does not usually provide a measure of total movement of the dump which may be a vital parameter in addressing certain stability modes.

Thus, it appears that this is an opportune time for the industry to consider the use of other monitoring methods and instrumentation in an attempt to improve the situation. In addition, the proper implementation of monitoring should reduce the number of costly dump failures and allow dumps to be designed and operated safely at minimum overall cost (including the cost of failures) measured over the life of the dump.

This report discusses instrumentation in the following categories:

a) Movement, pressure, pore pressure and other physical measurements of the state of the dump.

b) Data acquisition, transmission and reduction hardware and software.

In addition, a chapter of "pointers" discusses common mistakes with respect to specification and installation of frequently used instrumentation types. Recommendations are given for instrumentation for different classes of dumps relative to the B.C. Dump Guidelines classification scheme.

The report discusses a wide range of instrumentation which is available as well as some which appears promising but which is still in the research stage. In addition to instrumentation, the report also discusses drilling, since recent advances in drilling methods allow the use of some instrumentation methods not previously considered due to the difficulty of drilling into or around dump material.

Specific recommendations for instrumentation include the following:

a) <u>For Class II and III dumps:</u>

- Use of wireline extensometer combined with vertical monitoring of stands (tripods).
- Use of EDM.
- Use of visual monitoring.

b) For Class III and IV dumps, monitoring of both vertical and horizontal components of movement on the dump surface using instrumentation selected from the following:

- Use of wireline monitoring combined with vertical monitoring of settlement of stands (tripods) and a good understanding of the mode of failure. Correction should be made for the affect of different failure geometries on the apparent movement rates measured. Buried extensometers provide a useful alternative when combined with a system of vertical monitoring.
- Use of EDM.
- Use of visual monitoring.

- Use of vertical movement monitoring on the dump surface.

- Methods which provide both components of movement over a period of time are recommended. At present this includes EDM but in the future will include GPS.

- All Class IV and most Class III dumps should incorporate measurement of piezometric pressures in the foundations except where the foundation materials are not sensitive to the development of pore pressures. Stress cells should also be considered.

For Class III and IV dumps, it is important to measure both components of movement (vertical and horizontal) to allow measurement of the actual movement rates. Measurement of the total movement over time at selected locations is also important to allow a complete understanding of possible failure modes and deformation characteristics.

There are a wide variety of data acquisition methods and data transmission methods available, some of which can be incorporated into the mine's other transmission and control systems.

New developments to watch in the next few years include:

a) GPS (Global Positioning System) combined with the use of a reference baseline. This is capable of accuracies of ± 5 mm in three dimensions. Prices are falling quickly.

b) Acoustic monitoring.

c) Videometry and laser cameras.

Significant advances have been made in the subject of instrumentation, yet the present instrumentation methods used on dumps have serious disadvantages which likely contributes to a relatively high rate of major failures. It is recommended that some of the methods discussed in this report are worthy of trial and further development.

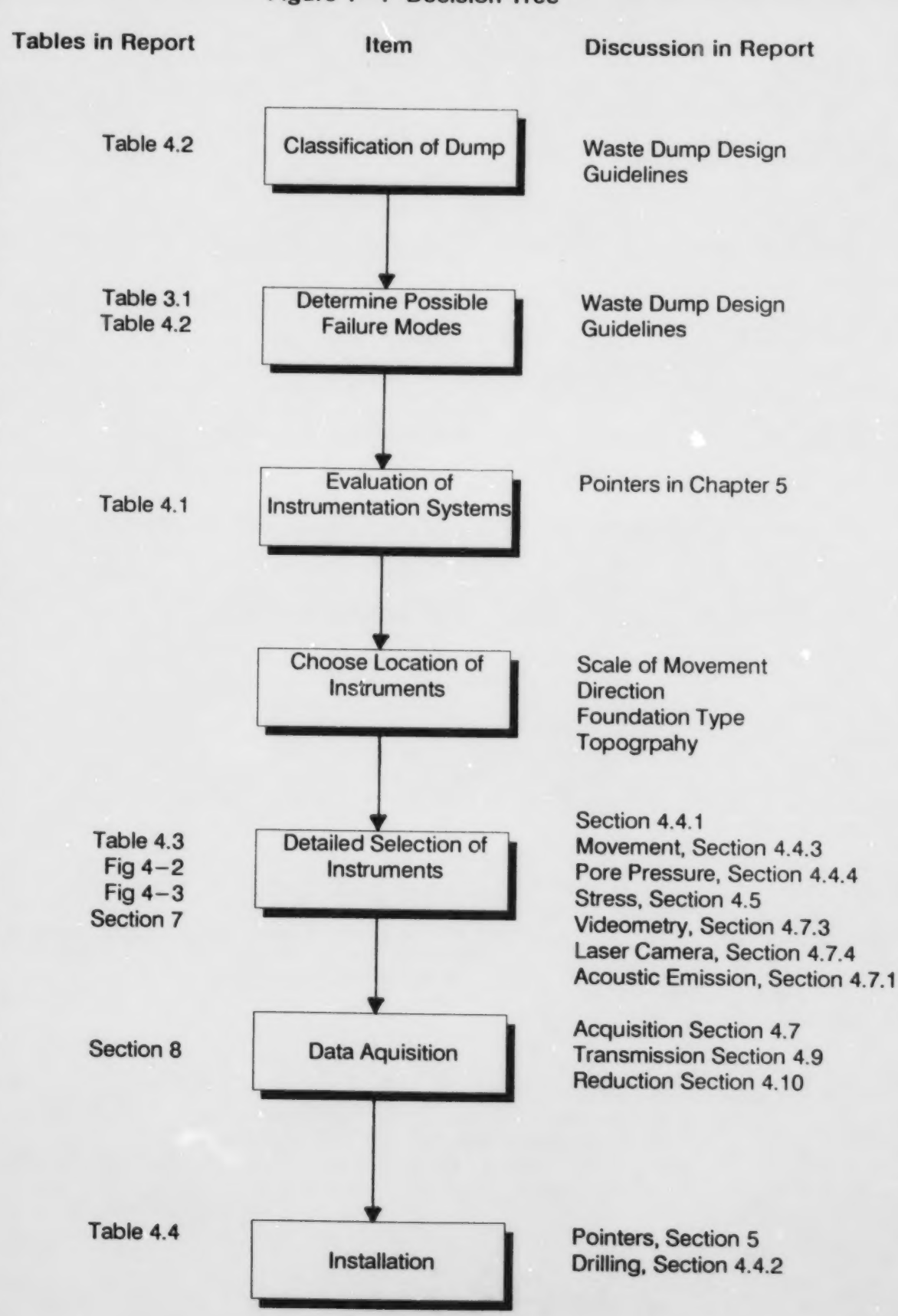
1.2 Report Organization

This report is organized into the following overall categories:

Subject Area		Sections	
Summary, Introduction, present status		1 and 2	
Instrumentation requirements and recommendations relative to dump classification		3 and 4	
Pointers		5	
Discussion and Recommendations		6	
Instrumentation data sheets	Physical Monitoring	Movement:	7.1
		Pore Pressure:	7.2
		Stress or Pressure	7.3
		Other:	7.4
	Data Handling	Data Acquisition	8.1
		Data Transmission	8.2
		Data Reduction	8.3
References and List of Suppliers		Back of report	
Tables		Oversize at back of report	

Large tables are at the back of the report. Figure 1-1 shows a decision tree for implementation of a monitoring program which has been annotated to show the location of different material in this report.

Figure 1–1 Decision Tree



1.3 Acknowledgements

The authors wish to acknowledge the following additional individuals and companies who provided input into the report:

a) Dr. E. McRoberts and Mr. C.O. Brawner who reviewed the report and provided critical comments.

b) Ms. D. Cheveldeaw who did the drafting.

c) Input from hundreds of individuals and companies all over the world who supplied volumes of information which has been distilled into this report.

The opinions expressed in this report are those of the authors. Numerous trade names are used in this report. These names are registered to the users of the name or trademark. The mention of a particular product does not imply that there are not other similar products as good or better than those mentioned.

2.0 INTRODUCTION

2.1 General

The purpose of this report is to summarize the findings of a study into monitoring technology for mountain dumps. Waste dumps are large piles of waste rock and smaller amounts of soil representing non-ore bearing materials which are excavated in the process of uncovering the ore-bearing rock. The large waste dumps which are the focus of this report may be over 350 m high and would normally be constructed as a result of open pit mining activities as compared to underground mining.

For the purposes of the project, high dumps, such as those found in mountainous mining environments, are of the most interest. These dumps are often built on the sides of steep slopes and have special design and monitoring requirements. However, many of the monitoring technologies that have been identified are not restricted to use on high mountain-type dumps and may be applied in a number of situations including all surface mines as well as other civil engineering applications such as embankment dams.

The technologies discussed in this report originate from current waste dump monitoring practice, from related areas of geotechnical engineering and from technologies developed for other engineering applications. In some cases, the report also discusses technologies which are not fully developed but which may offer useful and cost effective methods for monitoring waste dumps in the future.

This report is one of several studies related to dump stability, construction and monitoring which are in various stages of preparation at the time of writing. The other studies are:

a) A draft of "Waste Dump Design Guidelines for Mines in British Columbia" was prepared by Piteau Associates and was available in mid-March, 1991. This report is referenced as the B.C. Waste Dump Design Guidelines in the present report. It is presently (early 1992) available as the "Mined rock and overburden piles - Investigation and Design Manual" available from the B.C. Ministry of Energy, Mines and Petroleum Resources.

b) A technical guide for the operation of waste dumps in B.C is in preparation by Klohn Leonoff Ltd. A draft copy of the report was available in mid-March,

1991. This report is referred to as the B.C. Waste Dump Operational Guidelines report in the present report. It is presently (early 1992) available as the "Mined rock and overburden piles - Operating and Monitoring Manual.

c) A review of major waste dump failures and preparation of a data base is being undertaken by Mr. S. Broughton as part of a Master of Engineering program at U.B.C.

d) Golder Associates has been awarded a contract to study the "Runout Characteristics of Debris From Dump Failures in Mountainous Terrain".

2.2 Terms of Reference

The detailed terms of reference for the work covered in this report include the following:

a) Review of literature and contact with appropriate Government agencies, equipment manufacturers and leading experts in the field to ensure that monitoring and data interpretation approaches used elsewhere in related areas, as well as apparently unrelated areas, are included in the study.

b) Contact with mine operators to solicit current monitoring and data methodologies, past experience with alternative approaches, and ideas for different approaches. This will also include review of the use of the Observational Approach (Operational Approach), limitations on the use of more sophisticated monitoring approaches, and discussion of when it is appropriate to use more advanced procedures.

c) Examination of developments in monitoring instrumentation that could find application in monitoring live waste dumps and dump foundations.

d) Examination of developments in data transmission and automated data interpretation technology that could find application in monitoring active waste dumps.

e) Critically review, on the basis of performance, cost, reliability and practical feasibility, any particularly attractive alternatives to existing monitoring and data interpretation practices identified in the study.

HBT were notified of the award of the project by telephone conversation on Jan. 10, 1991 and the formal contract was received and signed on Feb. 15, 1991. On the basis of the original schedule established by CANMET, the final draft report was due on Mar 31, 1991. The schedule was extended in mid-March by Mr. A. Stokes of CANMET. The final comments on the draft report were received early in February, 1992 at which time the final copy of this report was prepared.

2.3 Purpose of Monitoring

Various reasons for monitoring waste dumps may include the following:

a) Regulatory requirements: While regulatory requirements may require a certain level of monitoring, the best benefit to the mining company will occur, if the other benefits of the monitoring as discussed below are incorporated into the overall dump plan.

b) Lower Costs: A comprehensive monitoring plan may allow reduction in the factor of safety of the dump, particularly of interim slopes within the dump. This usually is associated with lower dumping costs and may result in overall savings to the mine.

c) Safety: Improvement in worker and equipment safety.

d) Environment: Less risk of damage to the environment due to dump failure.

e) Dump behaviour: Better prediction of dump scheduling and phasing through improved understanding of dump behaviour.

f) Research oriented monitoring to improve understanding of dump behaviour over time.

As suggested above, development of comprehensive dump monitoring programs may result in lower costs to the overall mining operation due to reduction of the indirect costs of a dump failure in addition to allowing the dump to be operated at the minimum factor of safety that is consistent with good practice. In order to realize these benefits, the information contained in this report should be combined with information contained in other publications regarding the design and operation of waste dumps.

2.4 Methodology for the Study

The study was undertaken primarily as an office study augmented by the experience of the authors with respect to waste dump operation and design. Visits to local manufacturers and distributors of key information were undertaken; however, neither the budget nor the timing of the work allowed field visits to operating mines or other sites.

A key part of the study was the various sources of information which are outlined in the following sections.

2.4.1 Sources of Information

A wide variety of information was used in the course of this study. Sources of information included the following:

a) Survey of mining companies throughout western Canada, the US and elsewhere. The survey concentrated on companies with high dumps directly applicable to this study.

b) Survey of consultants, instrumentation companies and drilling companies. This survey was sent to various organizations internationally.

c) A large number of contacts were made by telephone with people with potential input to this study. These contacts were distributed throughout the world.

Table 2-1 provides a summary of the above activity. Where information supplied by respondents or contacts was directly used in this report, a reference has been made and additional contact information is contained in the annotated list of references.

Table 2-1 Summary of Contacts During Preparation of Report

Category	Area	Numbers sent
Mining Companies	Canada - Western	36
	Canada - Other	9
	U.S.A.	4
	Other (Australia, etc.)	4
Instrumentation Companies	Canada	14
	U.S.A.	15
	Other	11
Consultants	Canada	17
	U.S.A.	23
	Other	36
Other Organizations (inspectors, drillers)		13

As a result of the initial survey, over 100 additional contacts were made with personnel throughout the world. In addition to the HBT questionnaire, HBT was furnished with draft copies of the Guidelines for Waste Dump Design by Piteau Associates and the Operational Guidelines by Klohn Leonoff. Information from these reports has been incorporated into this document. In addition, information contained in a survey of B.C. mine operators undertaken by Piteau Associates in connection with their work has also been used in conjunction with survey data from the HBT work in the preparation of this report.

Other sources of information included the following:

a) Searches of bibliographic databases on the CAN-OLE system maintained by the National Research Council of Canada. Several different databases were searched including the Engineering Index, NTIS and Coal sources. There were few new direct references to dump monitoring, but several interesting papers and sources were found.

b) In-house files and a database maintained by the authors for their personnel use which contain a number of references to new technology in monitoring.

c) Information from other engineers and sister companies within the AGRA organization. AGRA is the parent company of Hardy BBT Limited.

The various contacts generated by this process provided information from all parts of the world.

2.4.2 Survey of Existing Monitoring Technology

Existing methods used for monitoring waste dumps in B.C. are summarized in the B.C. Waste Dump Design Guidelines. The information was made available to HBT through the Ministry of Energy, Mines and Petroleum Resources in Victoria, B.C.

In addition, as part of the current study, a number of other mines and consultants have been contacted in North America, Europe, Australia, Asia, USSR and Africa. The contacts were both by written survey as well as by telephone. The results of the various contacts and surveys are summarized in the following comments.

North America

Existing monitoring technology for waste dumps in the mining industry is generally simple and frequently some variation on the Observational Method (Peck, 1969) is used, although the use and constraints of the Observational Method are not always recognized.

Typical monitoring methods are as follows:

- Surface movement monitoring using simple mechanical devices, or survey methods. The movement record is typically incomplete at any given location.

- Less commonly, piezometric pressure in the foundation material is measured.

The degree to which the measurements are correlated with analytical methods varies, but in many cases the movement data is assessed according to "rules of thumb".

The respondents to the survey indicated that in general there is satisfaction on the part of the mines with the existing simple approach for the majority of dumps.

The results of the surveys indicate that some dumps in B.C. are not being monitored, except visually. Of the remainder, most are being monitored using the wireline

extensometer (sometimes termed a tripod monitor, MCM or mechanical crest monitor) with some also being monitored using EDM (electronic distance monitoring) or piezometers. In a few cases, unusual technology, principally data acquisition, is in use or being tried.

The HBT survey was principally designed to produce information about new or novel monitoring techniques which were in use or proposed for use. The results of the survey with respect to the general overall level of technology were similar to the results reported in the B.C. Waste Dump Design Guidelines.

Where dissatisfaction was expressed with regard to the present methods, the comments fell into a few categories:

a) Concern regarding cost.

b) Desire to use data acquisition techniques to reduce costs.

c) In a few cases, mines see an increased need for piezometric monitoring.

d) In many cases the response was that the present system of monitoring was adequate.

Table 2-2 summarizes the responses from the HBT and B.C. Waste Dump Design Guidelines with respect to dump monitoring on high dumps in western Canada. In reviewing the information on the table, note that the mines surveyed were different since the B.C. Waste Dump Design Guidelines work surveyed all operating mines in B.C. and HBT surveyed all mines with high waste dumps in Canada. In addition, the responses are with respect to individual dumps for the B.C. Waste Dump Design Guidelines Work and with respect to mines (possibly several dumps) for the HBT survey.

Responses from consultants that were contacted around the world indicate that the simple methods outlined above are in common use. In general, it was ascertained that there was minimal concern with the issue of monitoring and only a nominal amount of instrumentation is currently being used. A few very unusual techniques were found. Specific comments for different areas appears below. It should be remembered that the height of dump, geology, topography and climatic conditions vary widely among the different parts of the world from which replies were obtained.

Table 2-2
Summary of Results of HBT and B.C. Waste Dump Design Guidelines Surveys as Applicable to Dump Monitoring

Item	HBT Questionnaire		Piteau Questionnaire	
	%	Number (Mines)	%	Number (Dumps)
1) Dump Height				
>200 m	24	4	15	10
100-200 m	18	3	26	18
50-100 m	35	6	24	16
<50 m	6	1	35	24
2) Type of Monitoring				
None	12	2	7	6
Visual	24	4	43	37
Wireline Ext.	29	5	37	31
EDM/Survey	24	4	9	8
Other	18	3	4	3
No response	12	2		
3) General Rating of Monitoring Performance.			Not available.	
Satisfactory	69	11		
Partly satisfactory	19	3		
None	12	2		
4) Unstable Dumps Reported	25	4	31	27
5) Interest in data acquisition	41	7	Not available.	
6) Experience with drilling into dumps.			Not available.	
None	69	11		
Failed attempts	19	3		
Successful attempts	12	2		

Note: 1) 16 respondents to HBT questionnaire refer to generalized "mine" experience.

2) 19 respondents to survey in the Design Guidelines refer to 85 individual dump case histories.

Southern Africa

In southern Africa it was noted that there was no major concern about dumps as they are usually located on flat ground in undeveloped parts of the country. The main concern was with the kimberlite diamond mines in Botswana where dumps were limited to about 47 m height due to pore water pressures in the dump causing sloughing above that height. Monitoring was limited to the installation of piezometers in the toe of the dump and monitoring of surface movements (Blight, 1991). Some wedge failures have occurred on dumps founded on a weak basal stratum of clay. Standard survey methods were generally used for monitoring displacements. Automated recording systems have been developed locally (Carter, 1991). Some failures have occurred in coal waste dumps but without major consequence (Blight, 1991).

Australasia

In Australasia the major failures were in mines located in high rainfall areas of Papua-New Guinea. A major dump failure was reported at Oktedi Mine. Monitoring is carried out using piezometers with data acquisition (Alangerak, 1991). In Australia, major dump failures are rare and most mines are located in remote arid areas where a dump failure would result in little damage.

The coal mining areas of New South Wales use valley fill type dumps but have had no stability problems. Higher dumps in Queensland (up to 40 m) are in relatively dry areas and no major failures have been reported. Stability of dumps is not a major concern and it is reported that minimal monitoring is currently being conducted (Lama, 1991).

USSR

In the USSR (survey done in early 1991), it is reported by the Mining Institute of Moscow that dumps up to 400 m high exist. Movement monitoring is restricted to wireline extensometer and EDM techniques. Pore water pressure measurements are made using piezometers. Some aerial photogrammetric monitoring has been used for stability control. In general, it appears that there is a lack of instrumentation and a shortage of funding. Interest in data acquisition/transmission was indicated. Weak dump soils are investigated using a mobile penetration logger (presumably some type of drill rig) (Calperin, 1991).

Western Europe

In western Europe the main mining areas are located in West Germany. Coal mine waste dumps of up to 100 m high exist in the northern part of Germany. There are also some temporary structures of limited height from the lignite mines where waste is stored temporarily prior to backfilling the pits (Wittke, 1991).

Some stability problems have been recorded in the past but the shear strength characteristics are well defined and foundation conditions have been established. No major stability problems existed at the time of the survey and monitoring of the dumps was limited to the use of extensometers and surface levelling techniques. Inclinometers have not met with success due to the magnitude of displacements associated with the waste dumps. No new technology is being used at present apart from the use of what are believed to be fluid type settlement gauges.

Great Britain

Reports from Great Britain indicate that the relatively small waste dumps around the country are not currently giving rise to any significant problems. Regulations place the responsibility of monitoring active dumps on the mining company. All closed dumps are monitored by a consultant appointed to the task (Hake, 1991). The level of monitoring is minimal, being limited to the simple visual techniques, utilizing an excessive number of mining engineers available in the industry. Acoustic emission monitoring is being developed for dump monitoring, in part to identify and locate the surface of movement within the dump (Gray-Stephens, 1991).

Italy

It is reported that SIS Geotechnica (SIS Geotechnica, 1991) is monitoring a waste dump in Italy using newly developed software and data acquisition equipment.

Scandinavia

In Scandinavia, there are apparently no large waste dumps and it is the practice to backfill open cast mines with the waste product. It was reported that there was no major concern about stability of existing dumps and so the level of monitoring was minimal (Lejion, 1991). There are a large number of high earth and rock embankment dams to retain water. Conventional types of instrumentation are installed in these structures. Surface tiltmeters have been installed in rock fill dams using a steel

beam fixed directly on the face of the dam in areas of concern. Laser techniques are used to monitor dynamic motion. Data acquisition and transmission are used to monitor major structures and some interesting software packages are being developed by the Norwegian Geotechnical Institute (Dibiagio, 1991).

3.0 MONITORING OF WASTE DUMPS

3.1 Observational Method

Waste dumps are frequently constructed using the Observational Method. In many cases, the method is abused, not understood, or is not fully implemented. It is therefore useful to review the "Observational Method" as originally defined by Terzaghi and discussed by Peck, (1969). The Observational Method is well suited to mining projects where informed risk taking is an understood and necessary element of the economics of development. It is recommended that the Observational Method should be explicitly used in the construction of waste dumps.

The basic steps in the Observational Method for design and construction of waste dumps consist of:

1. Undertake field and office investigations sufficient to establish conditions and design for dump. Assess likely and worst case conditions and the response of the waste dump to these conditions. (Design Stage).

2. Base design on the most probable response considering the rating system in the B.C. Waste Dump Design Guidelines. The more state-of-the-art the issue, the more useful the Observational Method is as a way of handling uncertainties (Design Stage).

3. Define and select quantities, factors and measurements to be taken as construction proceeds. Calculate or predict the anticipated values of the monitored parameters under the most likely prevailing conditions and under unfavourable conditions. These monitoring limits form the basis for caution, for stopping dumping, or for changing the design when construction is proceeding. (Design Stage).

4. Select a mitigative method or response for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis of behaviour. These responses can be adjustments to dumping procedures, berms, drainage and so forth. These responses must be defined beforehand. They cannot be left to the operational phase, although it is clear that actual field conditions will always suggest modifications to the initially conceived responses (both Design and Operational Stage).

5. Devise a monitoring system that allows clear and timely observation of the selected parameters (Design and Operational Stages).

6. Proceed with construction. Ensure that an appropriate system is in place not only to collect data but to act on it. This requires close cooperation between geotechnical engineering, mine engineering and operations staff. A management commitment to the method is mandatory to ensure that the process is in place and is respected by all those involved. Regulatory overview to ensure that this process is occurring is also important.

7. As monitoring data is collected and construction proceeds, use the monitoring data to control the rate of dumping and to evaluate the overall design. Modify dumping procedures and design as appropriate and re-evaluate the monitoring procedures.

It should be noted that certain aspects of the Observational Method are vital to its correct application:

a) A feedback loop from design to monitoring/evaluation and back to design.

b) Mitigative procedures which are formulated at the time of design for every conceivable unfavourable circumstance. These procedures may be later modified as construction proceeds.

c) Monitoring which furnishes the required data to evaluate conditions in the field and which is used to control modifications to dumping or to the design.

The selection and application of monitoring instrumentation forms one part of the application of the Observational Method to the design and construction of waste dumps.

3.2 Applicability of Monitoring Methods Discussed

The monitoring methods discussed in this report fall into one of the following categories:

a) Currently applicable instrumentation, methods and software. This includes off-the-shelf items which are ready to apply as well as instrumentation which may require some modification or adaptation to apply to a dump. The systems presented range from the very simple and inexpensive to state-of-the-art systems that would be applicable only to certain dumps.

b) Methods applied in other fields which have direct application to waste dump monitoring.

c) Areas of current research which appear to be promising but which are not currently available (due to technical, economic or practical reasons) for application to dump monitoring.

d) Areas which at the present time appear to be "dead ends" not applicable to dump monitoring. Also included in this category are methods which may have very limited applicability.

It is stressed that some of the methods in all of the foregoing categories are applicable only to monitoring some dump situations. In particular, there is no one method of monitoring, including those methods currently in use, which is generally applicable to all waste dump monitoring situations. The main reason for this is that the different methods are sensitive to different types of movement (different movement vectors) and that different failure modes characteristically exhibit different movement patterns.

The intent of this report is to document the current state-of-the-art and to indicate possible future directions that appear to be promising based on the information available during compilation of this report. In addition, technologies that offer only minimal promise are also summarized briefly since this may prevent someone else from wasting time pursuing an alternative which is not promising. It is also possible that others may find a way to apply the technology.

3.3 Waste Dumps in Mountainous Terrain

Figure 3-1 from the Design Guidelines shows typical dump configurations. Of the various types of dumps shown, all but the heaped fill are normally applicable to mountain dump situations. As discussed in the B.C. Waste Dump Design Guidelines, many of the mountain dumps in B.C. are classified as valley fills of some type (Types a to c on the figure). A similar situation would apply to mountain dumps in Alberta.

High dumps include dumps for open pit coal mines as well as for metal mines. Typically, the coal mine dumps have exhibited greater stability problems than the metal mine dumps (B.C. Waste Dump Operational Guidelines).

Figure 3-2 shows a typical cross section of a mountain dump. The height of many of the mountain dumps exceeds 200 m and the highest dumps exceed 350 m. The dumps typically contain material ranging up to several meters across and are constructed in end dumped lifts which may vary from a fraction of the dump height to full dump height.

3.4 Typical Failure Modes

Typical failure modes are shown in the Design Guidelines and are amplified in Table 3-1 attached at the end of this report. The table also shows the typical deformation characteristics for different failure modes. In many cases, the pattern of deformation provides valuable information regarding the possible failure modes which should be considered.

It should be noted that deformation of the dump does not necessarily indicate failure. All dumps are placed in an initial state which is relatively loose. After the initial placement, the dump material then undergoes compaction as the particles rotate or break and fit closer together. (Note that "compaction" is used here in the geological sense and does not imply the application of external compactive effort, as in placing an engineered fill.)

On the basis of observations, the total vertical movement for a high dump may be at least 2 m. This predominantly vertical movement is also likely accompanied by a small amount of lateral strain, although measurements of lateral movement within the body of the dump are seldom conducted.

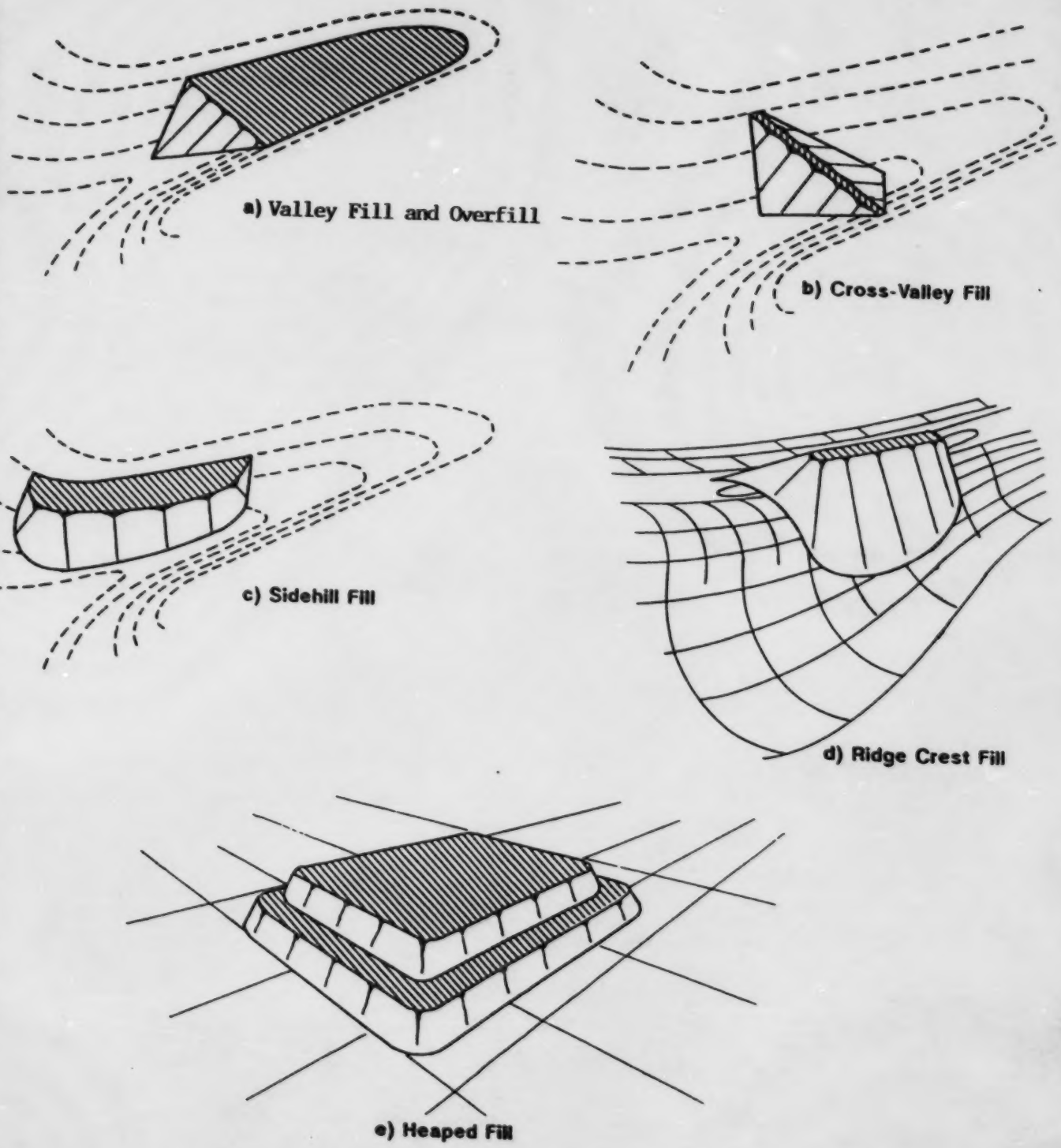
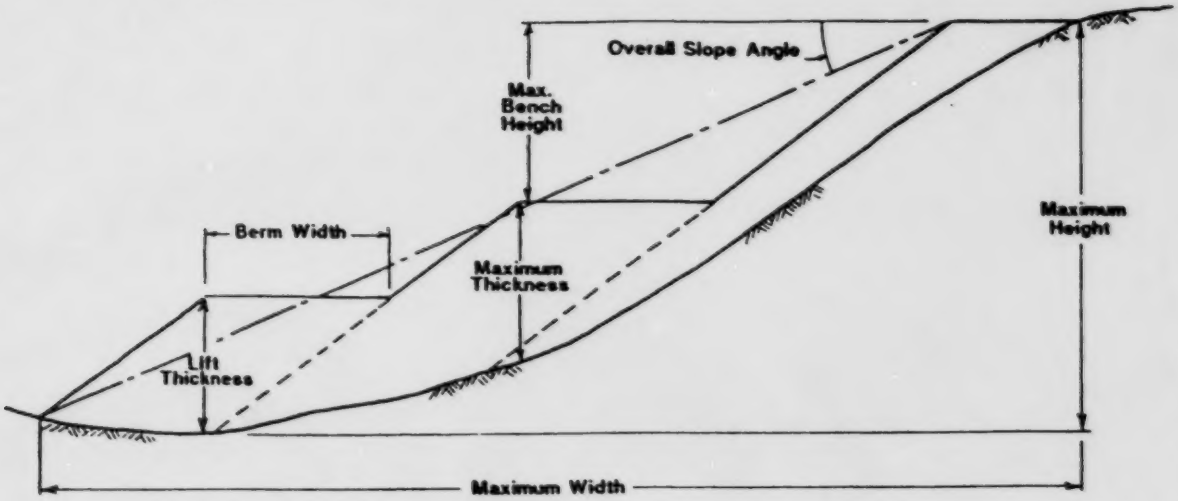


Figure 3.1 Typical Waste Dump Configuration
(from B.C. Waste Dump Design Guidelines)

EXAMPLE 1

TYPE OF DUMP	METHOD OF CONSTRUCTION
Sidehill Fill Benched	Initial Repose Angle Lift with two lower wraparounds



EXAMPLE 2

TYPE OF DUMP	METHOD OF CONSTRUCTION
Open Pit Backfill Benched	Multiple Lift Repose Angle Benches

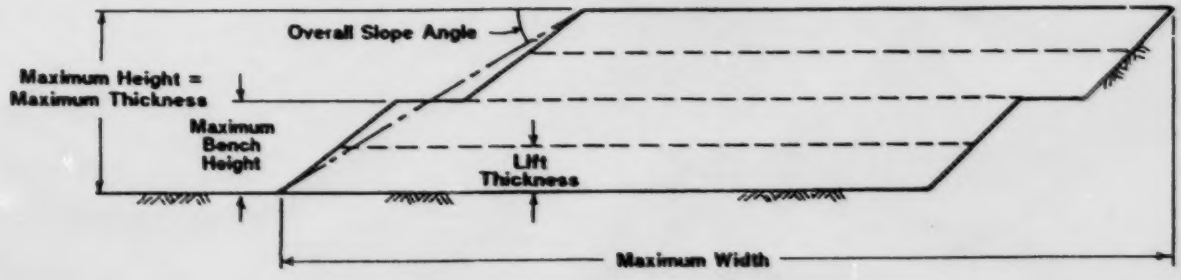


Figure 3.2 Typical Cross-sections of Waste Dumps
(from B.C. Waste Dump Design Guidelines)

According to comments by Seed (1975), coarse grained dumped rock fills might be expected to undergo settlements in the order of up to 5 %. Due to the way in which dumps are constructed, which typically involves end dumping on an inclined surface, much of the settlement would be expected to occur before the dump is constructed to full height on any particular vertical section. Nevertheless, it is apparent from observation of settlement cracks on dump surfaces, that dumps undergo appreciable vertical movement which is not related to failure.

The large vertical settlement movement poses problems for the use of many conventional geotechnical instruments since many instruments installed in holes through the dump material would be distorted or sheared off over time. The susceptibility of different types of instrumentation to differential movement is indicated in Table 4-3.

Dump movements may occur for several reasons including the following:

a) Settlement of the dump material over time as discussed above. This would normally have minimal shear displacement, although tension cracking of the surface of the dump may occur, particularly above abrupt changes in the original ground topography.

b) Consolidation of underlying soils, particularly peat and lacustrine deposits.

c) Shear movements within the dump. Most dumps exhibit some shear movement and a key reason for monitoring is to prevent the small shear movements from accelerating to become large, uncontrolled movement (failure).

A key to the correct interpretation of monitoring results is the separation of the settlement movements from shear movements resulting from instability within the dump. There is no infallible rule to do this, although analysis of the movement vectors provides useful information.

3.5 Problems with Current Monitoring Practice

This section discusses principal concerns with respect to current monitoring practice. The discussion in this section is based in part on the results of the written and telephone surveys and partly on HBT's assessment of the current state-of-the-art.

Concerns with respect to the existing level of monitoring include the following:

- Collection of Movement Rate Data vs. Movement Amount: The wireline extensometer (tripod monitor), which is the most frequently used monitoring method, is usually used to collect rate data rather than total movement data. While the wireline extensometer is a very useful piece of equipment, the disadvantages of rate data compared to total movement data should be recognized. The disadvantages include difficulty of extrapolating to failure time, non-recognition of certain high-strain related failure modes and incomplete movement records for the dump. A major disadvantage of the system is the variation of reading with the direction of movement vector (discussed below).

- Reading variation depending on direction of movement vector compared to orientation of wire: If, as is often the case, the movement vector of dump movement is not parallel to the wire, the complete movement vector will not be measured. The proportion of the vector actually measured may vary from 0 to 100% in common situations. Also, greatly different movement rates can be determined with almost identical setups of the wireline extensometer depending on the location of the shear surface relative to the stands.

- Lack of internal data from within the dump: The status of the dump is usually determined from observed performance at the surface. The internal state of the dump is largely unknown. Useful data could include the deformation patterns, internal and foundation pore water pressures, stress conditions and the material characteristics.

- Lack of suitable technology for drilling in waste dumps: The commonly available technologies for drilling are often not successful in materials as loose and variable as waste rock waste dumps. Hence, some available instrumentation which could be of use is not generally installed within existing dumps.

- Disturbance of surface monitoring stations: Many of the surface monitoring methods suffer from the disturbance of reference points on the face of the dump.

The disturbance is related to the activity on the dump, rock falls/sloughs, and vandalism.

- Need to move surface monitoring points or instrumentation: As a result of surface activities on the dump, there is a need for frequent movement of surface instrumentation such as wireline extensometers (tripod type monitors). This results in a fragmented movement record with no record of total movement of the dump over the long term.

- Haphazard reading or no reading of monitoring equipment during periods of holidays, etc or after mine shutdown.

- Data acquisition/transmission and interpretation: The increasing cost of manpower indicates that there is a need for automatic acquisition of data from monitoring stations. The trend in the engineering industry is to consider remote acquisition and transmission to a central processing station. Continuous interpretation of data is perceived as necessary to cope with large volumes of data collected by automatic systems. Actual performance of the dump can be related to a design model of behaviour and a response routine may be used to check the performance of the dump against a predetermined model.

4.0 SELECTION OF MONITORING METHODS

4.1 General

This section discusses the general selection of monitoring instrumentation for use on waste dumps. In addition to material in this section, The following information should also be referenced:

a) Table 3-1, which discusses the detection of various types of waste dump failure modes using monitoring systems, and

b) the decision tree in section 1.2, which lays out the relationship between the tables and other information in this report.

General discussion of different types of instrumentation appears later in this chapter and details of different instrumentation systems and suppliers are shown on data sheets in Sections 7 and 8. Suppliers are shown in Appendix A.

The general planning and execution of setting up a dump monitoring program should include the following steps (adapted from Dunnicliffe, 1989). The execution of a dump monitoring program forms part of the Observational Method discussed in Section 3.1.

a) Predict mode of potential failures to be monitored.

b) Define parameters to be monitored and questions to be answered.

c) Select instruments and locations for installations to answer the questions in (b).

d) Assess factors that may influence measurements or lead to incorrect interpretation. Pay particular attention to the issue of the direction of the movement vector being monitored relative to the sensitivity of the instrument to that movement vector.

e) Prepare budget and plan installation including specifications.

f) Plan data collection, processing, interpretation and channels of communication.

g) Install instrumentation.

h) Calibrate/check instrumentation on regular basis.

i) Proceed with monitoring measurements and feed results back into Observational Method. This includes interpretation of the results, assessment, and decisions with respect to actions required.

4.2 General Requirements

General requirements of the two most widely used instrumentation systems are outlined on Table 4-1. Although the table discusses only the monitoring instruments themselves, the monitoring system may also include remote readout capabilities, data acquisition systems, or other systems. The comments on accuracy and related specifications apply to the overall monitoring system including any attached data acquisition equipment or readout devices.

Table 4-1 Summary of Typical Requirements for Common Monitoring Equipment

Type	Item	Typical Specification	Requirement	Comment
Movement	Accuracy and repeatability	±1 to 2 cm	Because of large movements due to settlement, does not typically need to be as accurate as movement monitors for conventional slope stability work.	Exceptions are situations where movement before failure is expected to be low. For example, failure of a foundation on collapsible soils.
	Long term stability	Drift < (accuracy and repeatability)	Long term drift may be highly misleading and should be as low as possible. The potential for drift can be a major problem in the adverse conditions of the mining environment and may occur for subtle reasons.	Calibration can be checked on external system such as an EDM or for some internal systems such as extensometers where the component most subject to drift may be the power supply.
	Cost	Mines require as low cost as possible. Many systems are not reusable (see additional comments in relevant sections).	Expense of instrumentation should be balanced against reductions in cost due to the ability to engineer the dump better (fewer catastrophic failures) and potential reductions in personnel costs.	Cost is highly sensitive in most mining situations.
Pore pressure (Piezometer)	Accuracy and repeatability	±0.3 m head	Typically similar to conventional monitoring of other geotechnical situations. Short response time is vital for most applications.	It is most important to seal the piezometer in the formation and to use correct techniques so that the indicated pressure is actually close to the formation pressure. Many piezometers are incorrectly installed
	Long term stability.	Long term drift < 0.3 m	Long term drift may result in incorrect assessments of dump stability.	Drift is different for different types of piezometer system. See detailed comments in Section 5.3 and related tables and data sheets.
	Cost	As low as possible. Note that most of the cost is in installation.	See comments above for movement monitoring.	The cost of the instrument is generally low compared to the cost of installation. Most piezometer systems are one-time-use.

4.3 Choice of System Relative to Dump Classification

Table 4-2 (attached to the end of this report) summarizes recommendations for monitoring requirements relative to the dump classification scheme put forward in the B.C. Waste Dump Design Guidelines. The most intense monitoring is recommended for the higher classifications. In addition, for Types III and IV, additional monitoring may be required to document certain key design questions which arise from the particular nature of the dump and its particular design requirements.

For dump types III and IV, the main recommended types of instrumentation are as follows:

a) Movement monitoring options: Wireline extensometer, buried extensometer and surface settlement. In the future, GPS combined with a reference line installed in the mine, will likely be used and will provide many advantages over present systems.

b) Rotation monitoring options: Surface tiltmeters for special circumstances. The use of downhole tiltmeters/slope indicators is generally not recommended except in special circumstances such as possible foundations which could fail catastrophically with little prior strain.

c) Pore pressures: The use of piezometers to monitor pore pressures in the foundation material and, in some circumstances, in the dump material, is recommended. Either pneumatic or electrical types may be considered, depending on the circumstances.

Future developments applicable to dump monitoring in the future will likely include the use of GPS. Other systems such as videometry and acoustic emission may also be developed to the point of economical usefulness.

4.4 Technologies Applicable to Dump Monitoring

4.4.1 Choice of Instrumentation System Relative to Monitoring Requirements

Table 4-3 (attached to the end of this report) summarizes instrumentation applicable to various measurements required for dump monitoring. Additional details on this instrumentation is given in the data sheets in Sections 7 and 8. Drilling is also discussed below, since the ability to drill a hole into or below the waste dump would allow considering the use of a wide range of conventional geotechnical instrumentation.

Table 4-3 does not provide recommendations on the use of data acquisition equipment for reading instrumentation installed on waste dumps, although the possibility of using a particular instrumentation system with data acquisition is noted. The choice of whether to consider data acquisition and/or the automatic reduction of data is mine dependant and does not depend on the choice of instrumentation type, although the particular instruments used may need to be compatible with remote readout.

Advantages of using data acquisition and/or remote reduction include the following:

a) Reduction in personnel costs, particularly where the monitoring period is increased to more intense monitoring on a 24 hour a day schedule. As the monitoring requirements become more detailed with the higher classification dumps, the potential benefits and cost savings of automated data acquisition become more attractive.

b) Uniformity in readings.

c) Ability to monitor on a more frequent basis and to examine the readings in the office.

d) Ability to set up automatic alarms and telephone warning systems if required.

A possible disadvantage is that there may be less visual monitoring of the dump if data acquisition is used, unless specific measures are taken to ensure that visual monitoring is continued.

4.4.2 Drilling

Currently, the results of the survey done during preparation of this report and the experience of the authors indicates that drilling into high waste dumps is seldom done due to the difficulty and cost of drilling. The difficulty is principally due to the nature of the material in the dump which often consists of large strong rock blocks with relatively large "pore" spaces between the blocks. Circulation is usually lost immediately for conventional drilling methods. The blocks may tend to rotate or move during drilling which further complicates the drilling of the material.

If it were possible to drill holes into the dump, either partway or into the foundation, the use of a wide range of conventional geotechnical instrumentation would be possible. It is likely that drilling into dumps will be easier in the future since a wide variety of new drilling techniques have been developed recently. Table 4-4 outlines the use of various drilling technologies which could be considered for use on high dumps. Note that some of the methods have already been applied to coarse rock waste dumps. Where the use of different types of instrumentation would require a drill hole, this is identified on Table 4-3.

There are two different drilling strategies for installation of instrumentation into or below the base of a large waste dump:

a) Directional or slant hole drilling from some location adjacent to the dump.

b) Drilling a near vertical hole through the dump material.

It appears that several new drilling technologies, either at the stage of being commercially deployed or still under development, will allow the drilling of holes into dump material. In some cases, the rig types identified in Table 4-4 are not immediately available in B.C. or western Canada, however, it is expected that this would change if there was a demand for the service.

On the basis of the present information, it appears that the most promising technologies use similar elements:

a) Capable of drilling a cased hole with the casing close behind the bit.

b) The use of air as the drilling fluid.

c) The use of percussion bits capable of drilling or breaking the large rock blocks that may occur in dump material.

d) For instrumentation purposes, it is desirable to have a permanently cased hole. Installation of instrumentation through the drill casing and bit with later withdrawal of the casing frequently leads to damage to the leads. Thus, from the perspective of instrumentation installation, the use of systems which install a casing and allow withdrawal of the bit and/or drill string is considered preferable.

The most promising systems are (not in order of preference):

a) A modified pneumatic rotary drill with large casing hammer (vertical holes). This system may have the disadvantage of trying to work through the bit.

b) Krupp dual head hydraulic rotary drill (vertical holes).

c) ODEX/ODS systems (vertical and inclined holes).

d) Barber dual rotary drill (vertical holes).

e) Navi-drill or other directional drilling (directional drilling into foundation from outside the limits of the dump).

4.4.3 Movement

The purpose of this section is to provide a summary of the various applicable methods available for monitoring movement for the dump. Details on these various methods are given in Section 7.1 (data sheets). "Pointers" are discussed in Section 5. This section summarizes the most common instruments.

Commonly used instruments are discussed below and are shown schematically on Figure 4-1. Additional instruments and information appears in Table 4-3 (attached to the back of the report). Several of the instruments discussed in Table 4-3 incorporate technology that appears to offer promise of good monitoring techniques for use in the future.

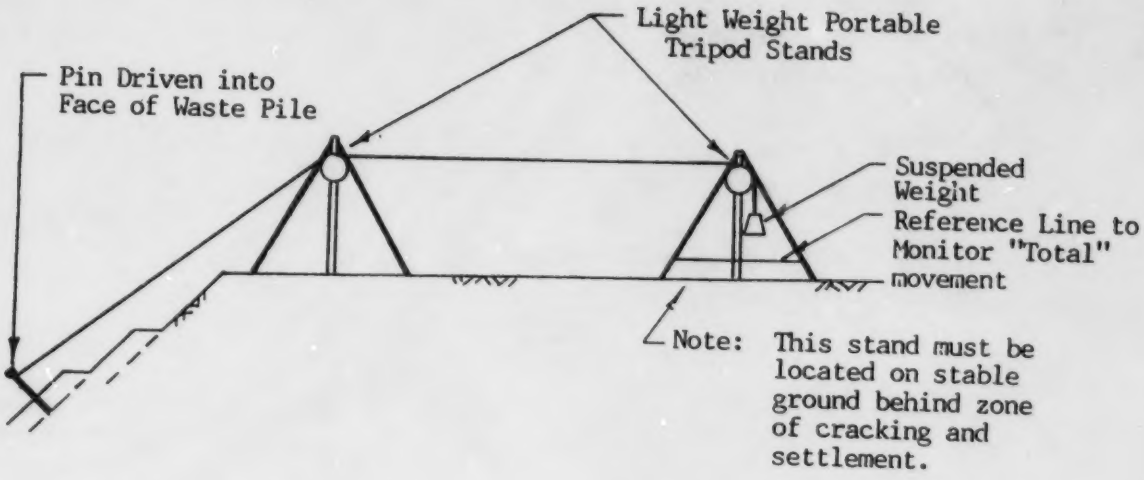
a) Wireline Extensometers: These may also be termed tripod monitors or mechanical crest monitors. This is the most common monitoring instrument

used on dumps in western Canada and would normally be found on any high mountain dump. Advantages include low cost, flexible and rapid deployment, and easy installation. Disadvantages include different sensitivities to movement depending on the movement location relative to the location of the stands (Section 5.2.1), the difficulty of monitoring a location for long enough to get a complete movement record for the dump, and disturbance from other activities on the dump.

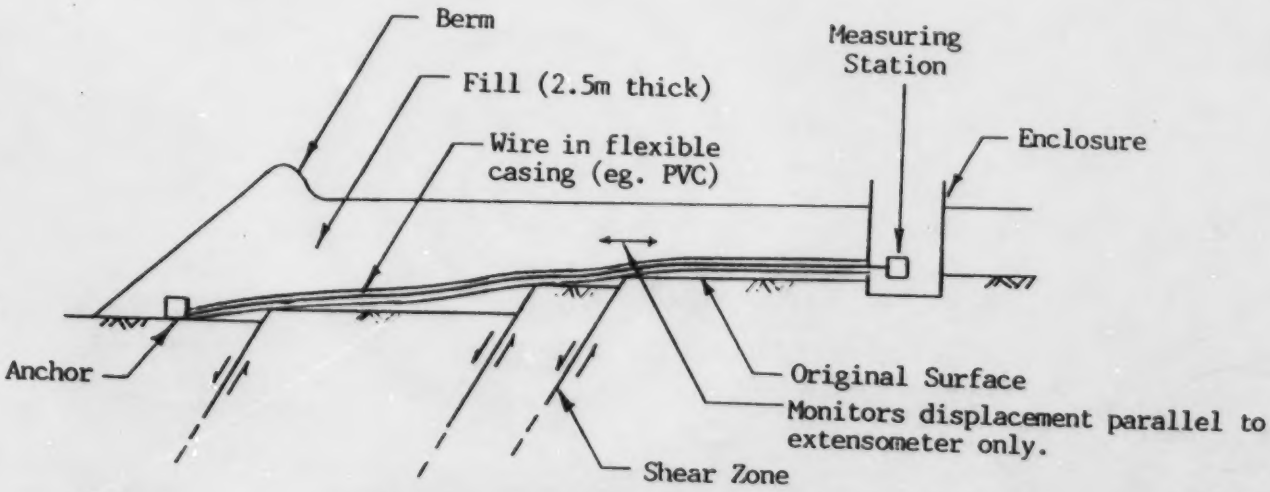
The attention of mine operators and regulatory personnel is particularly drawn to the information contained in Section 5.2.1 where it is concluded that if the wire is not parallel to the direction of movement, the extensometer will read between 0 and 100% of the actual slope movement, depending on failure mode. In the absence of consideration of the failure mode and the direction of movement relative to the wireline, the readings from the instrument are potentially misleading and the determination of dumping rates. The solution to this problem is to understand the weak points of the instrument and to use care in the reduction and interpretation of readings. As with any instrument, readings may be very misleading if not interpreted in a framework which includes understanding the various factors that can affect the readings. It is also recommended that in some situations, the use of additional monitoring techniques can resolve some of the problems with the instrument.

b) Buried Extensometers: These are conventional flexible type (coilable) extensometers or similar equipment modified for use on a dump. Advantages include availability, cost, adaptability to data acquisition and limited disturbance by activities on the dump surface. Disadvantages include the fact that the instrument only monitors movement in direction parallel to the instrument (usually horizontal) and potential problems with jamming at sharp corners. The same geometrical problems discussed above apply to this instrument.

c) Electronic Distance Measuring: Widely used for monitoring pit slopes, this technology may be applied to dumps. Advantages include availability and cost. In addition, this is one of the few "low cost" and commonly used methods that is capable of providing the full movement vector and thus overcomes one of the major disadvantages of the extensometer methods. Disadvantages of the EDM include potential problems with loss of sight lines to the prisms, potential loss of prisms and dust from dump operations obscuring the prism. Disturbance of prisms on the dump may also be a problem.



a) Wireline Extensometer (Tripod Monitor)



b) Buried Extensometer

Figure 4.1 Commonly Used Instruments for Movement Monitoring

Table 4-3 lists a number of other movement monitoring technologies, some of which are applicable to dump monitoring at this time and some of which offer promise for future use. Technologies that may prove useful in the future for routine dump movement monitoring include:

a) GPS (Global Positioning System, developing technology that allows determination complete movement vector).

b) Acoustic emission (AE, developing technology).

c) Electromagnetic Monitoring (EM, developing technology).

d) Settlement gauges (presently available). Allows monitoring of vertical movement which would solve some of the potential problems of wireline extensometers.

e) Surface tiltmeters (presently available). Applicable only to rotational failure modes.

f) Videometry and laser cameras (developing technology with promise for providing a three dimensional movement vector).

4.4.4 Pore Water Pressures

Pore pressures are an extremely important factor relating to the incidence of all forms of shear failure of the dump. Pore pressures are likely the single most important parameter in understanding changes in the stability of a dump. In many cases, pore pressures are also fundamental to the understanding of rate of movement in response to loading of the foundation material by the dump. Since pore pressures are widely measured in civil engineering projects, there is a good understanding of the problem and a wide range of available instrumentation.

Unfortunately, due to the difficulty of placing piezometers in the dump and foundation material, pore pressures are only occasionally measured on operating dumps. The section on drilling (Section 4.4.2) should be referenced for new drilling technologies which may simplify placing piezometers either in vertical holes through the dump or in directional or slant holes drilled from outside the limits of the dump. However, it should be noted that in many cases, it is desirable to know the pore pressures close to the toe of the dump, within the area of rapid change in dump loading conditions.

This area may be difficult to access with a drill hole but is well suited to installations made in front of the dump as discussed below.

Very useful data may be generated by installing the piezometers in the foundation material and then constructing the dump over the instrument location. This may be best way to provide piezometric data within the area where the loading conditions on the foundation are changing rapidly. Installations within this area provide very useful pore pressure response data which may be used to assist in determining allowable dump advance rates to maintain stability. Adequate lead protection for the piezometer leads is required (usually trenching combined with a protective berm).

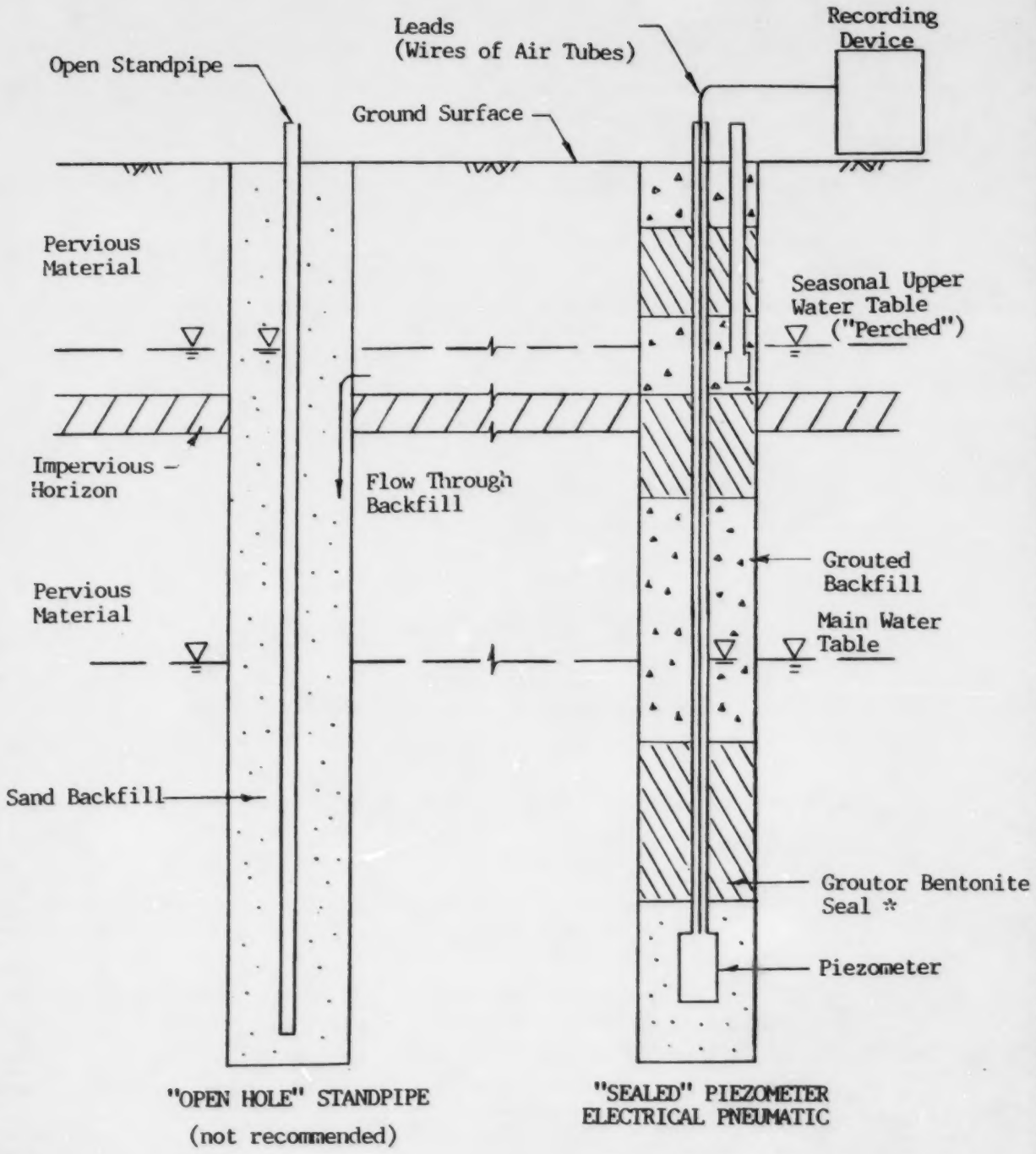
Pore pressure monitoring devices may be divided into two categories (Figure 4-2):

a) Instruments which are sealed into the formation and measure pore pressures at a defined point (piezometers), and

b) Open hole or well type standpipes which average pressures over a considerable length of borehole. The use of the latter instrumentation (i.e., open hole devices) is not generally recommended since the results may be highly misleading due to interconnections between high and low pressure zones. The only exceptions are for standpipes installed in formations known to be homogeneous or for water sampling purposes in near homogeneous formations.

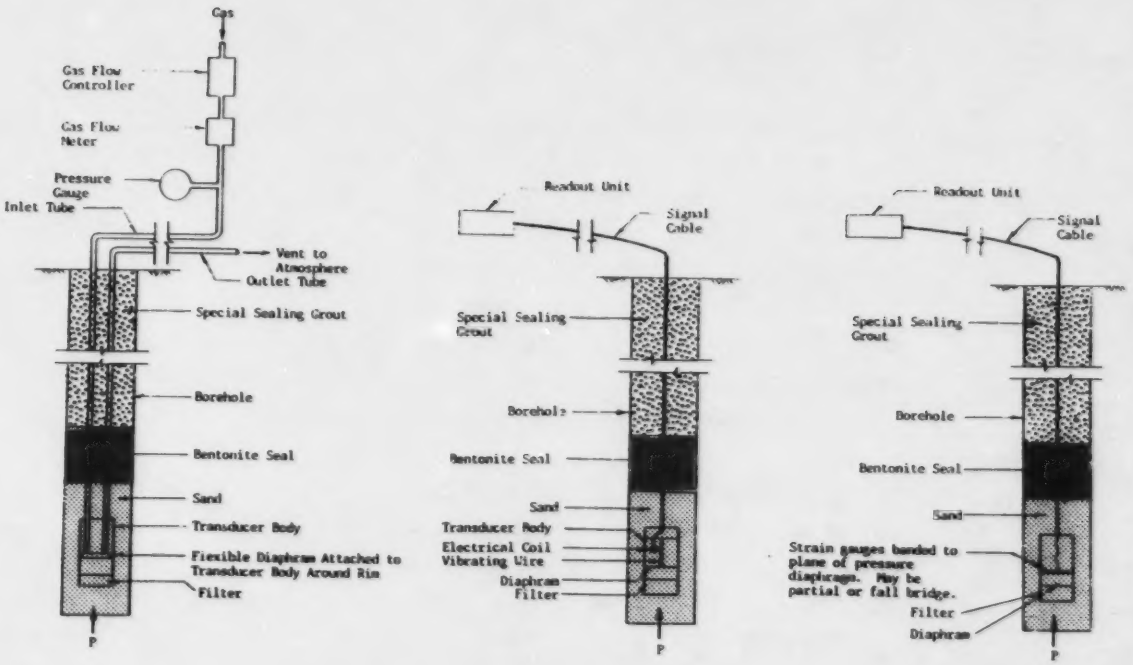
Piezometers are available employing a wide range of technologies to measure the pore pressure at a known location (Figure 4-3):

a) Pneumatic piezometers: These instruments operate by balancing supplied gas pressure across a diaphragm within the tip of the instrument. When the gas pressure balances the water pressure, gas flow to surface is either initiated or restricted, depending on the design. These instruments are stable, relatively inexpensive and will perform well in a variety of environments. Disadvantages include the need for care to see that the tube leads are not crushed or pinched (this will give a false increase in pressure) and the fact that integration with data acquisition equipment is more difficult.



* Note: Be careful of permeable zones by-passing seal. Seal must have atleast as low transmissivity as original ground. Inadequate seals are a major problem.

Figure 4.2 Piezometer Types



Pneumatic

Vibrating Wire

Electrical Resistance

Figure 4.3 Typical Piezometer Instruments

Note: Inadequate seals are a major problem. To be safe very long seals should be used, ideally extending most of the length of the hole or at least up to the next higher permeable zone.

b) Electrical Resistance Piezometers: These piezometers employ a diaphragm containing conventional strain gauge elements which read the strain induced by the deflection of the diaphragm and thus provide a reading of the water pressure acting on the outer side of the diaphragm. Disadvantages include lower long term stability for some instruments (many exhibit good long term stability), some dependence on lead length (depends on design), and the need for lightning protection (usually feasible). Advantages include low cost and rugged instruments. The instruments are capable of being read using data acquisition equipment providing that the lead resistance problems are allowed for, either in the design or in calibration.

c) Electrical Vibrating Wire Piezometers: These instruments use a diaphragm connected to a tensioned wire. When the diaphragm is subject to varying water pressures, the wire tension changes which in turn changes the frequency of resonance. The wire is "plucked" magnetically and the resonant frequency measured. Advantages include greater stability than the strain gauge units (debatable for some of the most recent strain gauge designs) and easy integration with data acquisition even for long lead lengths. Lightening protection is required but is usually not a problem. Disadvantages include the cost of the readout equipment and the base cost of the unit itself.

d) Standpipe Piezometers: These are pipe type piezometers which are sealed at a particular location in the formation to measure water pressure at a point. The advantage is that other tests such as infiltration tests or water sampling can also be carried out. The disadvantage is that the volume of water required to flow into or out of the pipe for a pressure change means that the water level will lag behind the real formation water pressure and that the installation of the piezometer may seriously affect the pressures in the vicinity of the tip in low permeability material. The result is that pressures measured by these units will be seriously in error for all but relatively permeable formations.

Variations on this type of equipment are the Casagrande (the original standpipe type piezometer) and Bishop types of piezometers which use small diameter tubes to limit the amount of water flow in and out of the instrument. These are complex instruments which are seldom used in present practice and are generally not recommended for installation on dumps where the maintenance required will likely not be done.

e) Multiport or Multilevel Piezometers: These are available from a number of sources and allow the installation of more than the normal two or three

conventional piezometers that it is feasible to install in a single borehole. The advantage is savings on drilling costs and the ability to make many more measurements in a borehole and thus gain a much better appreciation of pressure complex conditions. The disadvantage is increased complexity and higher costs. Depending on the model, there may be difficulty with integration with data acquisition. Some instruments, such as the Westbay system and the Waterloo system also allow other tests such as pump or infiltration tests to be made and may allow water samples to be taken.

4.5 Stress Cells

Stress cells consist of a flatjack filled with oil which is placed with the plane of the instrument perpendicular to the stress vector to be measured. The instrument is not recommended for general dump monitoring, however, if pore pressures are measured in the dump foundation, then placing one or more stress cells at the same time will alow the change in total stress to be measured.

Total stress changes result in pore pressure changes as a result on the foundation materials. The measurement of the total stress will assist in the prediction of pore pressures generated by dump loading. The only other alternative is to try to predict the loading imposed on the subgrade which is difficult for a sloping dump face which may not be straight and is continually advancing. If pore pressures are to be measured beneath the advancing dump face, then placing stress cells is also worth consideration.

4.6 Visual Monitoring

Visual monitoring is an extremely important part of any dump monitoring regime. With all of the emphasis on sophisticated methods, it easy to forget that visual monitoring offers some major advantages and should be viewed as a complimentary method to other more sensitive instrumentation based methods. Visual monitoring should be carried out on all dumps, irrespective of Class.

Recommendations for visual monitoring are contained in the B.C. Waste Dump Operational Guidelines. Any visual monitoring program should incorporate the following elements:

a) Systematic approach to observation of features, recording of information and cross referencing with other dump activity. Use of a table type of recording

format is useful providing that it does not become a crutch which results in the observer not thinking about what he is seeing.

b) It is useful to have the same team making the observations over a prolonged period of time with periodic review by outside personnel.

c) Comprehensive photographs properly labelled and filed are a vital supplement. It should be remembered that it is often as important that some feature is not present as if it is. Therefore, both general photographs of conditions, as well as specific items such as tension cracks, should be taken on a regular and ongoing basis. The use of cameras which automatically record the date will prove useful.

4.7 Other Technologies

4.7.1 Acoustic Emission (AE)

The concept of acoustic emission (AE) is relatively simple. As material slides and breaks, there is a "noise" which can be detected using simple accelerometers (geophones). AE is defined as "the transient elastic waves generated by the rapid release of energy within a material". The method was developed in the 1930's by the US Bureau of Mines during the study of rock bursts in underground mines due to stresses around openings.

Recent developments have been an extension of the techniques into monitoring of landslides and water retaining structures for stability, leakage, and cavitation. The method has been used successfully to predict failures in landslides (Jurich, 1975), coffer dams (deMonte, 1988), and to identify areas of fracturing within the foundation of dams (Carabelli, 1987). The equipment has been used frequently in mines to detect regions of failure (Blake, 1982 and Hardy, 1985). Schlumberger (1991) is working on equipment to detect the location of shear surfaces which would be applicable to dump monitoring.

Acoustic emission monitoring systems count and record the number of seismic events per sample interval which equal or exceed some preset threshold level of signal amplitude. In addition, if individual events can be correlated between three or more geophones, the location of the event can be determined. This requires processing of very large amounts of data in real time, but is becoming more feasible for a minesite with the availability of 386 and 486 PC computer equipment.

Acoustic emissions are attenuated rapidly in unconsolidated materials, particularly the high frequency events associated with stress release. The reception of the acoustic emissions is dependent on placing sensors in the vicinity of the potential movements. This can be done either by installing the instrumentation in the foundation of the dump initially or by installing metal rods (wave guides) to transmit the acoustic emissions to a point on the surface where the instrumentation can be attached. The wave guides may be a reinforcing bar, a metal piezometer standpipe/inclinometer casing or a borehole casing.

By means of an array of sensors covering the area of concern, the development of instability can be monitored and zones of potential failures can be predicted in advance of major movement. The disadvantage is that the quantification of movement is not possible and so the method should be coupled with a direct method of measurement of displacement. The method is well suited to data acquisition and transmission. Commercial units are available, although the most advanced units are still the subject of research and development.

At the present time, the use of acoustic emission being researched and there may be advances in the field in the future which make it a possibility for the detection of certain types of dump instability and also to detect the degradation of dump material as a result of shearing within the dump.

4.7.2 Electromagnetic Emission Monitoring

It has been established from studies in the geophysics of earthquakes that there is a release of electromagnetic (EM) energy (i.e. radio noise) when rock particles are fractured. The energy release has been monitored prior to the rupture of faults along which ground movement has occurred and in quarries following the detonation of a blast. EM emissions have also been measured in the laboratory when rock specimens are ruptured.

Many possible mechanisms have been postulated which could generate these 'seismo-electric' signals including piezoelectric effects, streaming potentials, Lenard splashing effects, plasma generation, electron emission, and separating electrification (O'Keefe and Thiel, 1991).

Research in EM radiation following blasting in a quarry site indicates that "a ... signal continues up to a minute after the blast. The signal is thought to be caused by relaxation of the rock behind the blast site. Each pulse would be a crack forming in

the rock. As the stress is released the number of pulses per second decreases". (O'Keefe and Thiel).

The method has potential benefit to the monitoring of waste dump slopes. The failures may be predicted within the mass of the dump where EM emissions may be occurring as a result of rupture of rock particles during the development of a failure zone. It may be possible that by means of an array of EM antennae throughout the dump, the areas of movement may also be identified. Research specifically directed toward dumps and slope stability would be required before this method could be recommended for dump monitoring.

4.7.3 Videometry

Videometry or videogrammetry (both terms are in use) refers to sets of video cameras used in conjunction with digital image processing methods to produce a technology that is capable of measuring the position, orientation and movement of objects in three dimensions. Videogrammetry can thus be used to model a waste dump by identifying visual features and tracking the movement of these features over a long period of time. The automated acquisition and analysis of the image data employed in such videogrammetric systems provides the capability of performing long term unsupervised monitoring, recording and early warning systems for waste dump movements.

Videogrammetry has been successfully applied to the monitoring of slope stability and other mining applications (Rudenhauer 1990, Chandler 1989). The resolution and accuracy of such systems is improving rapidly but varies widely with the application. Also, it is possible that the accuracy will not be sufficiently high to monitor the crest of a high dump from a location beyond the toe. A similar problem exists with the use of photogrammetric methods.

The use of videogrammetry provides potential advantages over conventional geodetic survey methods of waste dump monitoring by allowing the selective monitoring of specific regions of interest on the dump surface. Multiple regions of interest can be monitored with minimal incremental costs (i.e. the cost of a video camera). In addition, whereas other geodetic survey techniques provide estimates of motion on the slope for an array of individual targets, the videogrammetric method has the potential for obtaining a motion field, utilizing the tracking of many visual features identified on the slope surface. It is also a safe, passive method which does not have some of the hazards associated with laser techniques.

Disadvantages include the fact that the face of an active dump is in constant change. Thus, the method may be best suited to the monitoring of areas behind the crest (eg., failures daylighting behind the crest) or to monitoring of movements of the dump face at times when dumping is not going on.

Development of improved methods for videogrammetry are being carried out at the University of Victoria (McClean, 1991). The developments include an assessment of obtainable accuracy and determination of methods for field calibration of these systems. Commercial products which use these methods are being developed in Western Canada (Eos Systems). Advances in videogrammetric technology are being made in the traditional application areas once covered by the field of photogrammetry using new technology resulting from research in machine vision and artificial intelligence. As videogrammetry is implicitly based upon the computer analysis of visual information, it is well suited to data acquisition and transmission.

Videogrammetric systems can be employed for the three dimensional measurement of the waste dumps more or less independent of the size of the dump. Such systems acquire their basic data through still video imaging (taking still video pictures) of the dump from a variety of vantage points. This may be accomplished using a set of fixed permanent installations or a temporary platform such as a helicopter, the choice depending on the remoteness of the site, size of the dump, access and other considerations. These video images can then be processed to create any or all of the following:

a) Indications of shape change or target movement of the waste dump surface. These indications could take the form of an automated call and/or alarm to a local office or record data to a printer or file at the site.

b) A digital elevation model for the waste dump surface. This describes the surface shape of the dump. A series of such models could be stored to chart the time history of the surface deformation. This would include the detection of eroded areas, small scale landslides, progressive failure, as well as general settlement of the dump. Note that this digital elevation model would be an accurate three dimensional model of the dump. Measurements of the surface deformation could thus be made to compute local slope movements, and rates of movement in a real time model.

c) A digital stereo model of the pile. This consists of "draping" of the video imagery onto the digital elevation model created above. This would provide a three dimensional picture of the waste pile. With an appropriate display system,

one could the dump from a variety of vantage points and rapidly develop quantitative as well as qualitative judgements about the development of surface movements. Note that such a three dimensional picture or model can also include reference points adjacent to the dump, such as buildings and roads, and that distance measurement can be made relative to the reference points.

d) Various surface profile views of the pile can be created from the digital elevation model.

In summary, the videometry has the potential to provide a low cost, versatile, passive, safe and "easy to use" method of waste dump monitoring. This technology should be watched for possible future use as it is developed.

4.7.4 Laser Cameras

A laser range camera uses projected light and a video camera to measure three dimensional surfaces. The object is described by assigning X,Y,Z coordinates to each pixel of the image.

The equipment consists of a video camera and a laser projector which are set up on a known baseline. The laser is scanned across the field of view of the video camera. A computer positions the beam, tracks the beam in the image and calculates the coordinates of the points.

The application of the system is similar to the application of videometry as discussed above. At the present time, the range of the system is limited and could only be used on smaller dumps. Further development of the system could potentially allow its use on larger dumps. Disadvantages include the possible health hazard of the laser, depending on sight lines and the power of the unit, and the limited accuracy/range of presently available units.

Development of this technology is proceeding. At the present time, it would be suitable for application to small dumps. As the system development proceeds, the system may prove capable of providing useful data for large dumps.

4.7.5 Thermal Measurements

Thermal measurements may be required if the dump is constructed over permafrost or if the dump is expected to freeze in the future. Measurement of temperature is generally done using thermistor strings manufactured into cables with up to 8 to 12 beads per hole. In the past, thermistor strings for deep holes have typically been manufactured by certain consultants, including the authors, but are also available from certain instrumentation suppliers such as RST Technical. Inasmuch as the technology is only required for a few dumps, there is no detailed data sheet in Section 7.

4.7.6 Sampling of Dump Material

It is likely that sampling of dump material within the dump would provide useful information with respect to certain potential failure modes, such as liquefaction. The sampling of granular materials, such as the coarse granular material of a typical waste dump is at or beyond present levels of technology. Methods which could be considered include freezing (for saturated materials), various methods of injection and in situ testing methods. There is no presently available method that is clearly capable of providing this information at the present time. The sampling of very coarse particles is clearly not possible at the present time.

4.8 Data Acquisition, Transmission and Reduction

There is a large variety of equipment available in this general area, much of which was developed for purposes other than geotechnical use and some of which is unsuitable for dump monitoring. Much of the expertise in this area originates with work in monitoring dams and other hydrologic data. Recent papers by Purer and Steiner (1986), Silver and Rogers (1986), Dunnicliffe (1989), Hinckley, Tanner and Campbell (1987) and McCarter and Cameron (1985) provide interesting comments and case histories with respect to computerized slope and dam monitoring. No articles on automated monitoring of waste dumps were found in the literature, although there are some trials underway in western Canada which may furnish additional experience.

There are several different types of systems which may be considered for different applications:

a) Stand-alone systems which store the readings in the field unit. The readings may be downloaded either by access via telephone modem or by direct field inspection. This type of system is only recommended for dump monitoring purposes if the stored data is downloaded at regular frequent intervals. This type of unit may also be useful for supplementary data such as stream flow data.

b) Stand-alone systems which accumulate readings from other remote stations. These systems are similar to those in (a) except that there may be additional field units tied together.

c) Units which monitor and download in real time. These are more sophisticated units, often incorporating a variety of communication alternatives and using more sophisticated software. The prices are generally much higher than for the less versatile equipment discussed above.

Within the general field of data acquisition, there are three different functions: (i) data acquisition, (ii) data transmission and (iii) data reduction and interpretation. Most of the sophisticated units combine at least the first two functions into one integrated system. In the comments that follow, this equipment is discussed with respect to the separate functions. It should be understood that there are often advantages in using an overall system provided by one vendor.

4.9 Data Acquisition Equipment

A wide variety of equipment is available, both as stand-alone units as well as units which are part of a larger system. Some indication of the diversity of the available equipment is suggested by Table 4-5. One caution is that many of the units on the market were not designed for the demanding mining environment. In addition, many of the units on the market were originally designed for meteorological or hydrological use and the inputs often require input signals in the range of 0-5 VDC. The use of milli-volt type equipment, such as much geotechnical instrumentation, would require the use of preconditioning modules.

Additional discussion of data acquisition equipment appears in Section 5.4 (pointers for field equipment) and in the data sheets in Section 7.

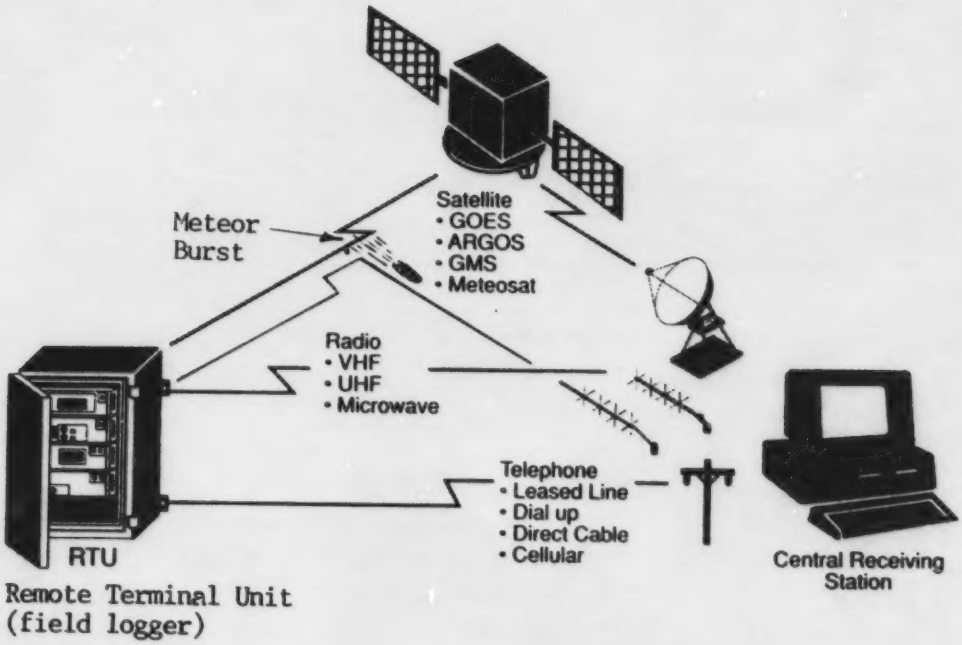


Figure 4.4 Typical Communications Options
(from Synergetics International)

4.10 Data Transmission and Associated Equipment

Information contained in this section is based in part on information supplied by Via-Sat Data Systems Inc. under subcontract to HBT as part of this project.

The last decade has seen phenomenal advances in the electronics industry. This has resulted in rapidly changing technology for automated data collection systems and communications. Although the manufacturers of these systems are continuously designing more sophisticated equipment, an automated data acquisition system continues to be comprised of three basic components. These are (Figure 4-4):

a) The remote terminal unit (RTU) and sensors.

b) The telemetry communications interface.

c) The control base station terminal or computer.

These components are discussed in the following sections.

4.10.1 Remote Terminal Unit and Sensors

The basic component of any real time data acquisition telemetry system is the remote terminal unit (RTU). These units consist of a power source, a microprocessor and an analog/digital (A/D) converter which provides an interface to the various sensors. RTU's allow data to be acquired remotely through telemetry communication systems or are able to store data in ram memory on-site for future retrieval. Storing data at the RTU for an extended period of time is not recommended for most dump monitoring situations due to the possibility of delay in interpreting critical data.

Almost any analog or digital sensor discussed in this report is capable of being interfaced with the RTU to provide a variety of field measurements. Note, however, that the interfacing of some instruments is easier than for others. Table 4-5 (attached to the back of this report) and the data sheets contained in Section 7 summarize various RTU units that are available. More of these units are coming on the market with time and the information in this report cannot hope to include all the units that are available. It is interesting to note that some of the most advanced equipment is designed and manufactured in B.C.

4.10.2 Telemetry Interface

Data sensed and stored at a remote terminal unit may be transmitted to a ground station in at least four different ways:

a) Satellite.

b) Radio.

c) Telephone.

d) Meteor burst communication.

These are discussed in the following paragraphs.

Satellite

The two satellite communications systems used in North America are the GOES (Geostationary Operational Environmental Satellite) and ARGOS.

The GOES system has operated since 1975 by NESS (National Environmental Satellite Service) of the U.S. Dept. of Commerce. The satellites in the GOES system are stationed above the equator. The satellites retransmit data received from a remote terminal unit to a central receiving station. Data is then made available to the end user via land lines. This service is offered free of charge to approved users and is formalized through written agreements between the user and NESS.

The ARGOS system is a joint French and American scientific satellite. This system consists of orbiting satellites rather than geostationary ones. This means that satellite communication is only available when the satellite is overhead. The ARGOS system does not provide data retransmission services free of charge. Quotations can be obtained from the satellite authority C.N.E.S. in Toulouse, France.

Radio

Data from remote stations can also be transmitted by radio telemetry. Radio options include the use of VHF, UHF, and microwave. The users of these communication systems have complete control of their systems and can transmit longer, more

frequent messages than if using satellite agencies. The reliable range is typically much less than for satellite communications.

Meteor Burst

Meteor burst communications is based on the phenomenon whereby radio waves will reflect off the ionized trails left by meteorites entering the earth's atmosphere. Communications are long range (due to the altitude of the trail) and are made in a short lived window whenever a suitable window is available. Suitable windows are about 10 seconds long and usually occur frequently (every few seconds). The information is relayed as a compressed packet in a "burst". Typical networks consist of a master control station and many remote stations. Frequencies in the 30 to 50 Mhz range are the most practical.

Two major data acquisition networks in operation today are the U.S. Dept. of Agriculture's SNOTEL system and the Alaskan Meteor Burst Communications System (AMBCS). Sierra Misco in Victoria operates a meteor burst ground station.

Telephone

Telephone line is likely the most economical means of data transmission. However, this would depend on the local services available at the remote station. As suggested in Figure 4-4, communications could be accomplished via a leased line, dial up, cellular or direct line. In addition, many mines have satellite up-link systems for phone communications which could also be used for data transmission via phone links.

Control Base Station Terminal

As discussed above, data retransmitted from a satellite is sent to a downlink receiving station such as the NESDIS Central Data Distribution Facility at Camp Springs, Maryland. With the use of appropriate computer software and communication lines, data is ultimately sent back to the users computer system. For example, such a system is used by B.C. Hydro to monitor reservoir parameters. Once within the user's system, additional analysis can be applied as appropriate.

Table 4-5 summarizes various RTU's and other data acquisition systems. Additional information on transmitting modules appears in the appropriate sections of the data sheets.

4.11 Data Reduction

The information in this section is based on discussions with equipment suppliers and other end users as well as HBT's general experience in the field. Useful papers on this area include Fairweather (1988), Purer and Steiner (1986) and Goguel and Ozanam (1989).

Key factors include:

a) Overall compatibility with other parts of the system.

b) Way in which the information will be used and interpreted.

c) Way in which alarms are implemented.

d) Warning of problems which develop at any point within the system.

The software that is available or in use may be divided into three categories:

a) Relatively simple software usually supplied as part of a data acquisition unit, that is capable of alarm functions and may provide plotting services.

b) Software, such as Lotus 123, which provides graphical services, but which does not provide a high level interface with the data acquisition unit. It is possible to combine existing communication programs with other programs such as Lotus 123 under a batch type program and to use the macro facilities in the two programs to automate the complete process of downloading and plotting. Such systems are usually custom configured by the end user.

c) Sophisticated software that automates the complete process from interrogation of the field units to plotting of the results.

There are certain developments in this field which should be watched in the future:

a) The U.S. Army Corps. of Engineers have retained Woodward Clyde Consultants to write a general instrumentation data reduction program. The program is not available at the time of writing (May, 1991)

b) There is a program available in the U.S. apparently written by Woodward Clyde which provides some data reduction capabilities. Repeated attempts to get

further information have so far been unsuccessful due to a reluctance to ship the program out of the U.S.

c) A program being written at the Norwegian Geotechnical Institute to reduce monitoring data (Dibiagio, 1991). This program is not yet available.

In general, the more sophisticated the software, the more likely that the software is part of a custom package intended for one manufacturer's system. Most manufacturers can provide some level of software support for their products. Nonetheless, there appears to be room for additional programs to provide the necessary functions at a reasonable cost. In addition to off-the-shelf software, custom software may also be commissioned in order to provide various functions. With the onset of the use of object programming, this will likely become a cheaper alternative in the future than it is at the present time.

5.0 POINTERS FOR INSTRUMENTATION INSTALLATION

5.1 General

The purpose of this section is to outline key problems that may occur during the selection or installation of some of the more common methods of monitoring. The purpose in the following section is not to provide an installation manual, but rather to outline some the key points where problems have arisen with past installations. The discussion covers only the commonly used instrumentation and does not include some of the new methods proposed for use on dumps in this report.

For further details of installation of instrumentation, see Dunnicliffe (1988) or Hanna (1985). Some of the manufacturers can provide additional information applicable to their instruments.

It is stressed that while the installation of many of the instruments appears to be straightforward, achieving an installation which provides the most accurate possible data and which does not provide misleading information requires the personnel. In cases where the installations or instruments are not fully accessible after installation (for example, piezometers and extensometers), it may be impossible to determine whether the instruments are functioning properly. A thorough understanding of the parameters to be monitored and the instrumentation is required. Experience with similar past installations is a major asset to the installer. Furthermore, it should be recognized that major economic decisions may be based on the installed instrumentation and that saving a few dollars may be false economy.

The following comments are not all-inclusive, but highlight some of the major problems which experience has shown tend to repeated.

5.2 Movement Monitors

5.2.1 Wireline Extensometer

The wireline extensometer (tripod monitor or mechanical crest monitor) is the most common form of instrumentation for dump monitoring. Unfortunately, the instrument suffers from significant differences in sensitivity to ground movements depending on the location of the slip surface relative to the location of the stands. This is further shown on Figure 5-1 and summarized on Table 5-1.

Specifically, the recorded movement rate may vary from 0 to 100% of the actual movement rate. Thus, relying on the wireline extensometer to provide movement rates for controlling dump shutdowns and dumping policy without understanding the affects of the location of the movement surface relative to components of the extensometer can give very misleading results.

A further problem with the instrument is that wireline extensometers are frequently moved so that they are in proximity to the location of active dumping. This portability is an advantage of the instrument, but the disadvantage is that if there is no other form of monitoring, then there is no complete movement record available for the dump. In many cases, particularly for Class I and II dumps, this may not be a serious disadvantage; however for a Class II or IV dump, this may give rise to significant problems. For example:

a) Large movements of the dump may cause degradation of the material within the dump, leading to failure via a variety of mechanisms.

b) The threshold rate to stop dumping may not be the same at small total strains of the dump compared to large strains.

c) Understanding of the relationship between pore pressure and dump loading rates may be obscured by the lack of a record of total movement records. This may lead to incorrect conclusions about allowable dumping rates with respect to pore pressure generation.

It is suggested that on Class III and IV dumps, the wireline extensometer should be supplemented with additional instrumentation capable of providing records of total movement amount and complete movement vector for a small number of selected points on the dump. At the very least, the vertical displacement of the stands and the wire anchor point should be monitored.

Table 5-1 Summary of Differences in Recorded Movement Rates for Different Types of Slides

Case (See Figure)	Angle of Movement Vector	Angle of Extensometer Wire	% of full Movement Rate Measured	Comment
Fig 5-1(a)	37°	30°	99%	Typical of shallow wedge type failures.
Fig 5-1(a)	60°	30°	87%	Typical of more deep seated failure intersecting close to face.
Fig 5-1(b)	60°	0°	50%	Typical of deep seated failure intersecting dump surface behind the dump crest.
Fig 5-1(b)	75°	0°	26%	Same case as above, but movement vector oriented more steeply.
Fig 5-1(c)	90°	30°	50%	Typical of extensometer installed specifically to measure movement on a crack from a wedge type failure.
Fig 5-1(d)	90°	0°	±0%	Worst case, could be better if the end of the extensometer is anchored to the front moving block.

Note that this table was compiled for the wireline extensometer for typical cases. A similar situation exists for all instrumentation which measures a component of the movement instead of the complete movement vector. Great care is required for the interpretation of measurements for any type of instrument which show only part of the movement vector. As discussed in the text, the use of a few supplementary measurements is recommended in situations where the direction of the movement is not clear.

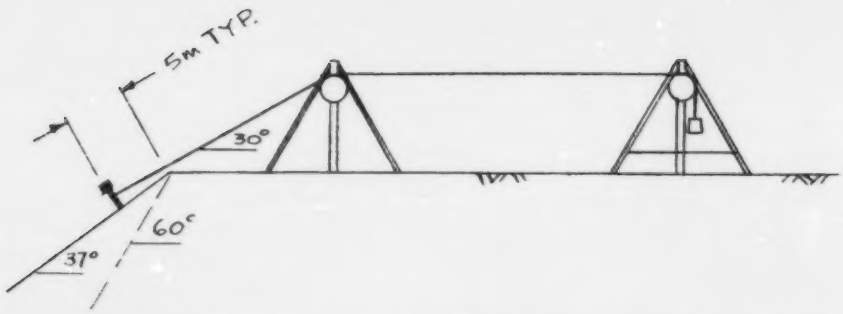


Figure 5-1(a) Slip surface close to the crest of the dump within the inclined portion of the wire. Under this scenario, wire is more nearly parallel to the direction of movement. 99 to 87% of the total movement rate will be measured for the 37° and 60° cases, respectively.

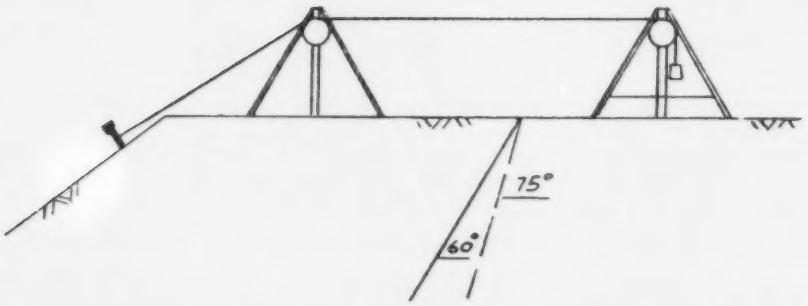


Figure 5-2(b) Deep seated slip surface intersects the slope farther back, within the portion of the wireline extensometer which is close to horizontal. It is assumed that the failure mass is moving as an intact block. 50% to 26% of the total movement rate will be measured for the 60° and 75° cases, respectively.

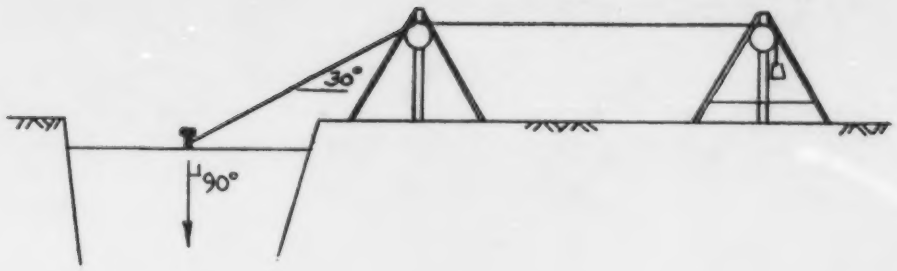


Figure 5-3(c) Wireline extensometer used to monitor a wedge type failure with the wire secured to the downdropping block and the last stand off the downdropping block. 50% of the total movement rate will be measured.

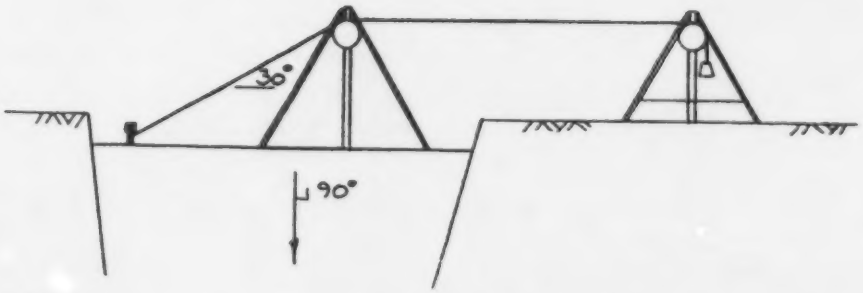


Figure 5-4(d) Wireline extensometer used to monitor a wedge type failure with the last stand on the failing block. The movement rate measured will be close to 0% of the total rate of the slide.

5.2.2 Buried Extensometer

At present, this instrument is less frequently used than the wireline extensometer for dump monitoring. However, it provides some advantages in terms of lack of disturbance to surface operations of the dump.

The following pitfalls may be encountered:

a) The information provided by this instrument is not strictly comparable in all situations with the wireline extensometer since the instrument only reads the component of movement since the wire is close to horizontal, compared to the wireline extensometer which has inclined portion of wire between the last stand and the anchor point. There is no change in sensitivity of the instrument with location of the slip surface as there is with the wireline extensometer.

b) Due to the construction of the instrument, it may be prone to jamming if the bends over shear surfaces become too tight (small radius). This problem may be reduced by careful instrument selection to obtain systems which are capable of relatively tight bends and may be further reduced by bedding the instrument between anchors in a loose or flexible medium such as clay, hog fuel (note possible environmental problems) or other media.

c) A man hole or other protection for the reading end of the extensometer will be required.

d) Compared to underground installation, the anchors are relatively simple and may consist of buried concrete blocks, plates or other measures.

5.2.3 EDM

The following suggestions are made with respect to Electronic Distance Measuring:

a) The choice of survey instrument is critical to obtain the best results. The following suggestions pertain to the EDM instrument and the associated theodolite:

- Use a 1 second theodolite. Less accurate theodolites are not capable of the same level of accuracy as the EDM and on long site lines will result in a large ellipse of uncertainty.

- Use permanent tribrach setup stations which are securely mounted.

- Some EDM instruments have been found to be more sensitive to cold temperatures and adverse conditions than suggested by the manufacturers' specifications. Cycle skipping and vertical or horizontal circle errors have been found to be common with some brands of instruments under mine operating conditions.

- The accuracy of the EDM instrument should be selected relative to the length of shot which is expected. In general, the accuracy requirements for dump surveying are usually less than for open pit surveys.

- The prisms should be selected for ability to return a signal at minimum cost. The use of mirror types rather than the more expensive ground prisms used for conventional surveying is usually found to be satisfactory.

b) Long term observations of prisms on dumps may be a problem, assuming that a location with a viable sight line exists. Potential solutions include:

- Use of a 0.6 m mounting "stalk" to raise the prism above the surface of the dump. Since the dump movement will be much greater than rock slope movements, the thermal and wind bending of the stalk will be relatively less important.

- Adjustment of the prism angle to maintain the prism "aim" will likely be required since rotation of the crest of the dump is common.

- As the dump is extended and additional fill is placed to correct settlement, it will likely be necessary to relocate the prism. Careful bookkeeping will be required to maintain the full movement record.

c) Depending on sightlines, it may be preferable to locate the instrument station on the hillside above the dump and shoot across the dump to shorten the sight lines relative to shooting across a valley toward the crest of the dump. This would be a typical situation in a valley side fill.

d) A major problem with the use of most EDM's is the intensive manpower requirements to obtain frequent readings. New automatic instruments on the market (see data sheets) are capable of providing readings to a data acquisition system automatically and will reduce this problem in the future.

e) Selection of sight lines is critical to obtaining the best accurate. For example, avoid shots which "graze" the edge of the dump due to potential diffraction problems. Shots across the sun-warmed dark surface of a coal dump may be very inaccurate. Under this circumstance, it may be better to survey in the early morning.

The method of data reduction is key to obtaining the best possible results. For example, Quintette Coal is using a statistical method of data reduction in which numerous readings of the same station are obtained to provide an ellipse of uncertainty for the station. The station is deemed to have moved when the apparent movement breaks the ellipse.

5.3 Piezometers

A large number of the piezometer installations which have been made are faulty for one reason or another. Key points during the selection of equipment includes the following:

a) Response time: Piezometers installed in moderate to low permeability materials should have low volume displacement characteristics. This rules out the use of standpipe piezometers in all but very permeable materials.

It should further be recognized that even for fast acting instruments, pressure equilibrium is still typically required to occur within the gravel or sand pack around the instrument (Figure 4.3) and that there will be some lag time for this pressure equilibrium to occur. In very low permeability materials (bentonitic clays or dense tills) the time required for equilibrium to occur may be measured in months, particularly if the gravel pack is not fully saturated.

The recommendation is to use low volume change instruments combined with good installation techniques to minimize the amount of air bubbles in the backfill or filter stone and to maintain the head in the hole close to formation pressure during installation. Standpipe piezometers should not be used except under special circumstances. See further details in Table 4-3.

b) Piezometer type: Most types are satisfactory, The decision should be made on previous experience, requirements for data acquisition, readout equipment availability and cost. Use of high air entry tips is not recommended. See Table 4-3 for a detailed discussion of piezometer types.

c) The use of standpipes not sealed into the formation is not recommended.

Pitfalls during the installation process are discussed below:

a) Placing materials in the hole: For piezometers installed in a borehole, it is vital that the location of all materials placed be checked. Gravel or sand filter material on the wall of the hole within the seal zone (Figure 4.3) can provide a leakage path for pressures to bypass the piezometer. Bridging of the hole can lead to complete loss of the installation. For deep holes, it is preferable to place

all materials into the hole through a tremie pipe in order to avoid contamination and loss on the sides of the hole.

b) Filter zone: This should usually be in the order of 1 to 2 m long. Great care is required for its placement.

c) Impermeable Plug or Seal: This is the key to a piezometer installation which provides a reading of pore pressure at a point within the formation. The plug can be placed of bentonite pellets or cement grout and should be at least 2 m long and should extend up to at least the next highest "impermeable" boundary. Experience shows that it is generally preferable to seal the complete zone between piezometers in a hole since detailed knowledge of the formation is often poor.

Some multilevel piezometers, such as the Westbay instruments, use special packer or grouted seals. The same comments with respect to length of seal also apply to these instruments, but the system may not be capable of providing a long seal. Bypassing of the seal may be a problem with Westbay installations in some formations.

Bentonite cannot be used at depths greater than 30 to 60 m, since the settling velocity of the pellets is such that they will swell and stick to the side of the hole before getting into position. Bentonite placed too fast into the hole will stick to the side of the hole and bridge. It is vital that bentonite pellets swell under confining pressure and the hole should be backfilled partially above the seal immediately after placing the pellets. Bentonite seals are often placed in zones which are too short (see comments above).

Cement grouts form a satisfactory seal, particularly in environments where the seal will not dry out. Interplast N should not be used due to the foaming which is induced in the grout. New grouts such as silica fumed grouts can be considered for use and offer advantages such as faster set. Care should be taken not to plug the grout lines.

d) Leads: It is most important that pneumatic leads should not be kinked in the hole since this will increase the apparent pore pressure read at the surface. Where pneumatic piezometers are installed under the dump, adequate protection is required to prevent the lead from being crushed. For installations below an advancing dump, there is some advantage to the use of electrical piezometers, since the lead integrity can be verified.

5.4 Data Acquisition, Transmission and Reduction

Desirable attributes with respect to data acquisition equipment include:

a) Power source Well designed battery powered units are capable of monitoring 12 sensors at one minute intervals for several months on small battery. The use of a solar panel can provide virtually continuous power in conjunction with a suitable battery up to at least 55 to 60° latitude. Transient protection from both lightning as well as power fluctuations from mining equipment (if applicable) is required.

b) Wide allowable temperature and humidity range. The mine environment is extremely severe as shown by problems that have been experienced with other equipment such as EDM's. A record of past successful installations is worth looking for.

c) Hardware reset and protection of user programs: microprocessor based equipment should be provided with a hardware reset to restore operation in the event that a transient or other malfunction interrupts normal operation. User programs should be in write-protected memory to prevent loss.

d) Field readable: it is vital that measurements can continue to be taken or verified in the field where data acquisition is used.

e) Signal conditioning: if signal conditioning is required (eg., conversion of millivolt input to volts level), this introduces an additional level of complication and expense. Equipment should be selected, if possible, that will directly accept the signal levels generated by the field equipment and instrumentation.

f) Topology: Systems range from very simple to distributed. In some cases, the signal transmission methods between the field units may not be compatible with field requirements (eg., use of a 4 wire connector across a dump surface).

g) Stand alone or level of automatic transmission/processing: Various levels of user dial-up or downloading vs. automatic transmission are possible. The key is that readings should not stay in the system for "long" periods of time without being plotted and input into the decision process.

d) Data transmission methods, if required. This requires detailed consideration relative to the particular requirements of the site.

e) Sensor excitation required by field instrumentation. The requirement for additional units other than those supplied by the manufacturer is an additional complication.

6.0 DISCUSSION AND CONCLUSIONS

6.1 Instrumentation

A wide variety of instrumentation is available for installation on dumps. Table 6-1 summarizes recommendations in this report with respect to instrumentation which should be considered for installation in different situations and also notes those systems which are not presently available but which appear to offer promise in the future.

The following additional comments should be noted relative to Table 6-1:

a) The table does not outline specific manufacturers. There are a number of manufacturers of equipment who produce similar products and the choice between the competing products depends on geographic area, cost, and the specific situation. Additional details of the different types of instrumentation are given in Tables 4-2, 4-3 and the data sheets in section 7.

b) The choice of use of data acquisition systems is an individual choice dependant on the circumstances in an individual mine. Some instrumentation systems are better suited to data acquisition as discussed in Tables 4-2 and 4-3, as well as the data sheets in Section 7.

c) Measurement of the total movement vector for at least part of the measurements is very important as discussed in this report.

d) Up to date plotting, interpretation of the readings and integration of the measurements into a system such as the Observational Method is very important.

Table 6-1 Summary of Recommendations for Different Types of Monitoring Instrumentation

Dump Class	Type of Monitoring	Presently Available Equipment		Equipment and Methods to Watch	
		Recommendations/Alternatives	Comments	Recommendations	Comments
I and II Note that other alternate systems shown in Class III and IV dumps could also be considered but are likely not justified.	Movement	Wireline extensometer possibly combined with either settlement monitoring of dump crest or of supports.	Note need for considering full (vertical and horizontal) movement vector relative to layout of wireline extensometer.		See additional discussion of alternate methods below. Most of these methods would be expected to be initially applied to Class III and IV due to the additional expense of applying new methods.
		EDM (Electronic Distance Measuring)	Need to allow for frequent readings as required.		
		Buried extensometer combined with settlement monitoring of dump crest (settlement instrument or survey)	Provides three dimensional movement vector.		
		Visual monitoring	Recommended in conjunction with all types of monitoring.		
	Pore Pressure	Piezometers in foundation or dump material as required.	Any fast acting piezometer. Standpipes not recommended.		
III and IV	Movement	Wireline extensometer in conjunction with provision for settlement monitoring of the supports and anchor point as a minimum.	Note discussion in report concerning problems with misinterpretation of data if full movement vector is not available.	GPS (Global Positioning System)	Expensive but costs dropping rapidly. Will be widely used in future. ±5 mm in three dimensions.
		Buried extensometer in conjunction with settlement monitoring (see below) of crest of dump.	See note above.	Videometry/laser cameras (two different systems)	Still to be proven. Provides three dimensional movement vector.
		EDM for selected locations.	Provides total movement vector but present systems are expensive for intensive monitoring.	Automatic EDM (Surveying Robot)	Available but expensive. Cost could be paid back quickly for intensive monitoring situations.

Table 6-1 Summary of Recommendations for Different Types of Monitoring Instrumentation

Dump Class	Type of Monitoring	Presently Available Equipment		Equipment and Methods to Watch	
		Recommendations/Alternatives	Comments	Recommendations	Comments
Class II and IV Cont'd	Movement, cont'd	Surface settlement. (Variety of methods available, see data sheets).	Provides vertical movement for use in conjunction with systems such as extensometer which are not sensitive to this movement vector.		
	Movement (Special cases)	Surface tiltmeters	Useful only for failure modes which involve tilting.	Fibre optics indicator, fixed electrolytic tilt cells (two systems).	Under development. Provides similar information as downhole tiltmeter but may be less susceptible to dump settlement.
	Pore Pressures	Piezometers.	Rapid response instruments using pneumatic, strain gauge or vibrating wire technology all recommended. Where installed in foundation of dumps, installation of earth pressure cells should also be considered.	Multiple point systems.	Westbay and Waterloo systems recommended for installation around perimeter of dump (but not through dump) where groundwater sampling is required.

See additional notes in text.

6.2 Data Acquisition, Data Reduction, Data Transmission

In general, the best data acquisition system will depend on the particular circumstances of an individual mine. Comments are given below on the various "generic" types of systems which could be considered.

a) Remote Transmission: Systems capable of remote transmission of data are recommended. If systems require a remote station to sign on to before dumping accumulated data, specific procedures should be put in place by the mine to ensure that data is interpreted and used in a timely fashion. Fully automatic systems have many advantages in this respect and their cost is becoming rapidly lower.

b) Method of data transmission: For most mines one of:

- Radio transmission, possibly combined with local radio nets already in place.
- Telephone transmission (including satellite telephone links) where the data is required off-site. Cellular transmission may a possibility at a limited number of mines.
- Satellite or meteor burst communications are only justified where the data is required off-site from distant sites without other methods of communication .

c) Type of System: System selection should be based on at least the following criteria:

- Suitable for the environment of application. Check batteries, temperature extremes, power requirements, electrical noise and lightning protection, water resistance, humidity requirements and case.
- Use systems which are designed to interface with the type of instrumentation to be used. Avoid signal preconditioning wherever possible. Avoid the use of separate power supplies for the instrumentation wherever possible.
- Avoid systems which require long wire runs unless adequate protection can be given. Be careful of long runs of wire which transmit analog signals.

- There should be provision for reading the instrumentation in the field.

d) System software: At the present time, most of the software is supplied with the data acquisition unit. The software should be tried with typical problems and instrumentation. There is an extremely wide variation in cost and features and many of the programs provide a lot of features which would not be required for a typical dump monitoring situation.

New software from third party vendors written to solve geotechnical problems may provide improved solutions in the future.

e) Data reduction: The traditional means of data reduction and plotting in many mines in the past has involved the use of Lotus 123 or similar programs. It is possible to automate the complete system using a communication program, batch files and additional third party key-stroke input programs. The process is cumbersome and other solutions such as third party software or software supplied with the data acquisition unit should also be examined. It is likely that the integration of different programs and modules will become simpler in the future with the increased use of object programming.

The ideal system would acquire the data, plot it and provide a warning if the trends exceeded preset limits. Such software is available for many of the data acquisition units shown in Table 4-5 and on the data sheets in Section 8. As discussed above, additional third party software is starting to become available and should be checked in the future.

7.0 DATA SHEETS FOR MOVEMENT AND PRESSURE MEASUREMENTS

This section of the report contains data sheets for key monitoring methods employing different principles. The sheets are based on data supplied by various manufacturers and are intended to be representative of the range of instrumentation which is available. However, it is stressed that there are, inevitably, additional types of instrumentation and manufacturers that are not included in this section, but which could be considered for use in a mining situation. In addition, the instrumentation manufacturing industry is highly competitive and, as a consequence, there is constant development and refinement of instrumentation and products.

Some of the information contained in the following sections refers to instrumentation and methods which are currently under development. Some of these methods were not commercially available at the time of preparation of this report, but the information is included since the methods appear to have promise. The organizations or individuals responsible for the development should be contacted for additional information.

The inclusion of information in this section does not convey any particular endorsement by HBT or CANMET of a particular product. The final decision to use a particular product or method, the installation of the equipment, and the interpretation of the data should be carried out by personnel experienced in geotechnical instrumentation and the interpretation of the results.

The sheets are organized within overall categories of movement, pore pressure, pressure or stress, other methods of monitoring, data acquisition, data transmission and data reduction. Within each section, there is a list of the data sheets and subjects included in that section.

7.1 Movement

The information in this section includes both conventional geotechnical instrumentation as well as the wireline extensometer and EDM equipment which is in common use in mining situations. Data sheets included in this section are as follows:

Data Sheet	Page
Wireline extensometer	7-3
Wireline extensometer modified by Modular Mining.	7-5
Rod or coiled type extensometer for buried use.	7-7
Sonic Probe extensometer	7-9
USBR Settlement Gauge	7-11
Vibrating wire settlement system	7-13
Double fluid settlement system	7-15
Borehole casing inclinometer	7-17
Optical fiber inclinometer (Light guide technology)	7-19
Fixed borehole inclinometer	7-21
Surface Inclinometer	7-23
Electrolytic surface tiltmeters	7-25
Coaxial Cable Shear Detector	7-27
Electronic Distance Measuring (EDM)	7-29
Surveying robot (Automatic EDM)	7-31
Semi-automated theodolite	7-33
Global Positioning System (GPS)	7-35

INSTRUMENT
WIRELINE EXTENSOMETER

SPECIFICATIONS
Wire, anchored at one end on the slope to be monitored or on one side of a crack, runs over one or two or more supports with pulleys, and weighted at the other end which hangs free. The weighted end is free to rise and fall, and deflections of the slope can thus be measured directly. See drawings in report.

MANUFACTURER
Usually manufactured onsite.

COST
Very cheap

TYPE OF MEASUREMENT
Slope movement data.

PRINCIPLE OF OPERATION
As the slope moves the free end of the wire rises. Measurements can be made against a fixed scale at the tripod.

UNIQUE ABILITIES
Cheap and readily installed and moved.

TYPICAL APPLICATIONS
Standard tripod monitor already in use in most mines in B. C.

INTERFACING
Usually a completely manual reading instrument. See Modular Mining Systems automated version.

AVAILABILITY
Universal.

CASE HISTORIES
Currently in use in many mines in B. C.

COMMENTS
The tripod monitor only measures the component of movement in the direction of the wire, and the sensitivity of the instrument depends on the location of the movement surface relative to the components of the assembled monitor.

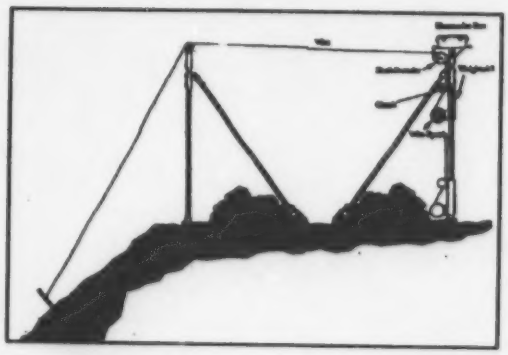
The wireline extensometer is a surface instrument and as such cannot be buried. There are inherent disadvantages caused by the required periodic relocation of the device. The movement record for the dump is incomplete if this is the only method of monitoring employed. Tripod monitors are also subject to damage and disturbance in their exposed location at the dumping face.

ASSESSMENT
Widely used and capable of providing useful data. Readings are often misinterpreted due to lack of understanding regarding movement vector problems of the instrument. Should be supplemented with vertical measurements of displacement at least at the location of the supports.

INSTRUMENT

AUTOMATED WIRELINE EXTENSOMETER

Modular Mining Systems - Tripod Slope Monitor System (SMS)



Tripod slope monitor

SPECIFICATIONS
Sensor: Optical shaft encoder
Accuracy: to 1 mm
Power: 13.8 VDC, 1 A
Operating Temp: -20 to 70 °C
Data Link: Integral 1200 bps radio modem

MANUFACTURER
Modular Mining Systems

COST
Typical system $3000 to $4000 per unit

TYPE OF MEASUREMENT
Modification of conventional tripod monitor widely used for dump monitoring to provide slope movement data from a standard tripod mounted wire slope monitor. Full radio telemetry of data combined with data reduction and alarms.

PRINCIPLE OF OPERATION
One end of a wire is anchored on the slope face, the other runs over a pulley and is reeled onto a drum. An optical shaft encoder mounted on the pulley wheel measures its rotation as the wire plays in and out. A data transmission package sends the information to a central computer via an FM radio net.

UNIQUE ABILITIES
Robust instrument, connected to FM net. Primary data analysis is done at the instrument, data is transmitted only when significant movement is measured. Runs on its own power source.

TYPICAL APPLICATIONS
Modification of standard tripod monitor which is the most widely used monitoring system in B.C.

INTERFACING
Compatible with Modular Mining Systems DISPATCH system.

AVAILABILITY
Modular Mining Systems Inc.

CASE HISTORIES
Presently being installed at Quintette Coal.

COMMENTS
Useful addition to the standard tripod monitor.

Note that the tripod monitor only measures the component of movement in the direction of the wire and that the sensitivity of the instrument depends on the location of the movement surface relative to the components of the monitor.

Note also that there are inherent disadvantages caused by the movement of the tripod to allow dumping in different locations so that the movement record for the dump is incomplete if this is the only method of monitoring. Tripod monitors are also subject to damage and disturbance due to their exposed surface location. See further discussion in the report.

The advantage of tripod monitors is that they can be quickly deployed and moved as required by dumping schedules.

ASSESSMENT

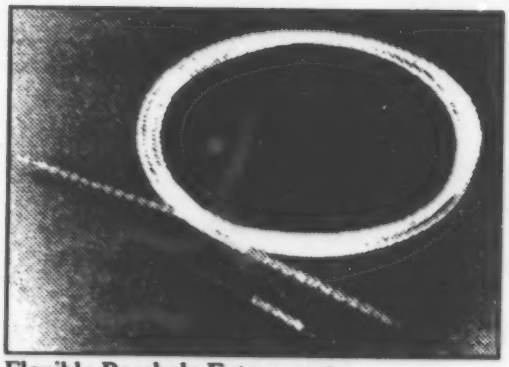
Useful addition to standard dump monitoring instrument. The limitations of the tripod monitor should be kept in mind. The use of other systems to supplement the tripod system is recommended for critical dumps.

The instrument provides instant alarm if movement is detected at the face. The data is sent to a computer for immediate reporting and assessment via the DISPATCH net.

INSTRUMENT

ROD OR COILED TYPE BOREHOLE EXTENSOMETER

Geokon - GK A-6
Solinst - MkIV
RST
Sinco



Flexible Borehole Extensometer

SPECIFICATIONS

Length:	infinite
Range:	2,4,6 in
Linearity:	0.1%
Accuracy:	0.5%
Resolution:	0.001 in
Number of sensors:	1 → 6

MANUFACTURERS

Geokon
Solinst Canada Ltd.

COST

Basic unit	$750

TYPE OF MEASUREMENT

For application in dump monitoring would be installed in a trench across the dump surface to allow measurement of lateral (horizontal) movement. Several anchor points could be installed. The anchor points should be concrete blocks or other points which will move with the dump.

PRINCIPLE OF OPERATION

Rods are anchored at one end and are free at the other (measuring) end. Movement of the measuring end of the rod relative to a fixed reference gives displacements.

There are a variety of different models available. Some use relatively stiff rods, while others are capable of being coiled for transport.

UNIQUE ABILITIES

This type of instrumentation allows measurement of horizontal displacement of the dump surface without interfering with movement on the surface of the dump.

There are a variety of similar instruments available from several different manufacturers. Most are capable of being interfaced with data acquisition, although this does require a supplementary reading head.

TYPICAL APPLICATIONS

Measurement of lateral (horizontal) dump movement.

INTERFACING

May be read with manual, or electronic strain or displacement meters. Reading can be automated.

AVAILABILITY
Off the shelf

CASE HISTORIES
Widely used in civil engineering applications and in mining for measurement of rock movement.

COMMENTS
This type of instrument has not been widely used of dump monitoring in the past but is recommended for intermediate and long term measurement of lateral dump movement (horizontal vector). Allows ongoing measurements to be made without interfering with work on the surface of the dump.

The ability of the instrumentation being considered to handle large movements should be checked before purchase. Modification of the standard reading head will likely be required since the standard head is designed for high resolutions but small movements (typically less than 0.3 m).

The coiled type instruments are probably preferable for use in dump monitoring due to greater ability to conform to dump settlement. Installation of the system in a clay filled trench would assist to reduce sharp bends which could result at tension or shear cracks.

ASSESSMENT
Recommended subject to comments above. Provides a means of measuring horizontal dump movement continuously over time to provide valuable records. A disadvantage is that the measuring point will not generally be right out to the active dump face and so other temporary methods will be required to supplement this system.

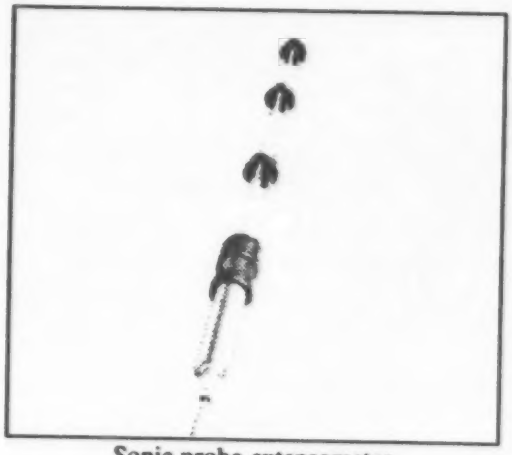
The length of the system relative to the size of a dump platform implies that the extensometer will have to be located in areas where shear movement is expected.

It is recommended that this system be combined with a surface settlement monitoring system where measurement of the complete movement vector is required.

INSTRUMENT

SONIC PROBE EXTENSOMETER

Geokon - GK 7000 series
Roctest - FMC



Sonic probe extensometer

SPECIFICATIONS

Anchors: groutable, mechanical, hydraulic, groutable hydraulic. Standard system would require minor modification for use on dump surface.

Hole diameter: 2,3,4 in.
Would require plastic or other casing.

Number of anchor points: 1-6,8,20.

Length: Flexible to 25 ft.

Range: 7.32 m

Accuracy: 0.5% of full scale

Operating temp: -7 → 43° C
(portable readout) for Geokon instrument.
-40 → 82° C (Roctest).

MANUFACTURERS

Geokon
Roctest

COST

Basic sonic probe	$500
Measuring Instrument	$4,000

TYPE OF MEASUREMENT

Measurement of horizontal movement on dump surface. Substitute under some circumstances for rod type extensometers.

PRINCIPLE OF OPERATION

On a dump surface the Geokon instrument would be installed in a trench with plastic casing to form a "hole". The Roctest instrument uses a single guide tube and would likely not require a casing, although use of select backfill would be required.

The anchors of the sonic probe extensometer contain permanent magnets. An electrical pulse in the probe creates a magnetic field which interacts with those permanent magnets to produce a torsional stress pulse which travels along the connecting rods in the hole at a known velocity. The measured travel time of the pulse is proportional to the distance.

UNIQUE ABILITIES

Measures differential elongations at up to 20 locations along the extensometer. Measures movement between anchors directly.

TYPICAL APPLICATIONS

Measurement of surface horizontal movement of dump over relatively short lengths (see maximum length of instrument).

INTERFACING

Geokon: The standard instrument uses a digital readout box which is not capable of being interfaced with other systems. In the-

ory, it would be possible to modify the box to allow interfacing with a data acquisition system.

Roctest: Capable of being interface with data acquisition.

AVAILABILITY
Off the shelf.

CASE HISTORIES
Has been widely used in mining environments, typically for underground use to measure movement of rock around openings. Has also been widely used for civil engineering applications.

COMMENTS
On the basis of the information supplied, the Roctest instrument is more flexible than the Geokon model. Also, the Roctest system appears to be more resistant to jamming under shear movement (vertical settlement of dump). It is noted that the models offered by different manufacturers are under constant change and development.

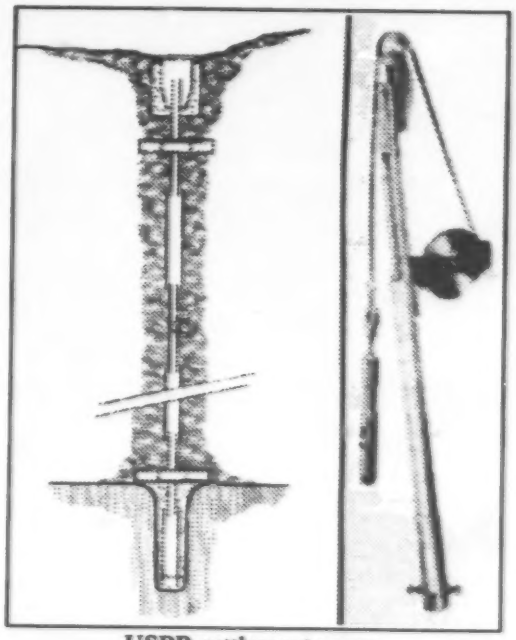
ASSESSMENT
Recommended for short range measurement of extension on the dump surface. Inherently more simple instrument than the multiple rod extensometers where more than one measurement point is required, but overall maximum length is less for presently available instruments.

Should be considered together with surface settlement monitoring systems where measurement of the complete movement vector is required.

INSTRUMENT

USBR SETTLEMENT GAUGE

Solinst mark II-S



USBR settlement gauge

SPECIFICATIONS
Tube: 50 mm i.d., with joint sealing tape, tube covers, and inspection cover

MANUFACTURER
Soil Instruments Limited

COST
Typical installation 100 m deep $5,000

TYPE OF MEASUREMENT
Settlement of surface plate relative to deep anchors.

PRINCIPLE OF OPERATION
A graduated tape with an attached torpedo is lowered into the tube. Retractable mechanical anchors in the torpedo grab anchor plates as the torpedo is extracted. Depth readings are taken off the tape at a reference at the surface. The standard system is designed for installation during fill placement so the anchors would require modification for installation in a borehole.

UNIQUE ABILITIES
Relatively crude technology but robust and proven.

TYPICAL APPLICATIONS
Limited application to dump monitoring.

INTERFACING
Reading has not been automated.

AVAILABILITY
Off the shelf.

CASE HISTORIES
U S Bureau of Reclamation.

COMMENTS
Widely used in dam and embankment construction. Could be modified to be used to measure dump settlement, but some problems, such as the telescoping tubes jamming together could be encountered.

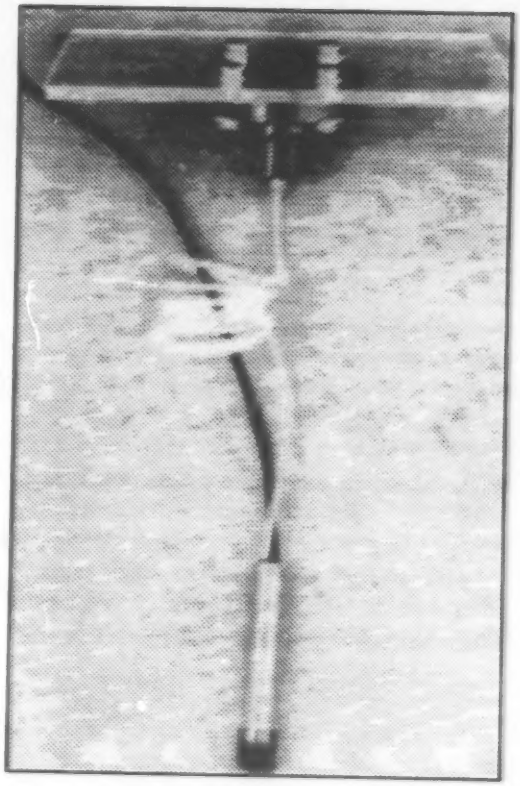
ASSESSMENT
Not generally recommended for dump monitoring. Could be considered for monitoring settlement of weak foundation soils or could

be modified to provide a profile of vertical settlement. There are instruments better suited to the purpose of settlement monitoring, although the cost will likely be higher.

INSTRUMENT

VIBRATING WIRE SETTLEMENT SYSTEM

Geokon - GK 4600,4650



Vibrating Wire Settlement Monitor

SPECIFICATIONS

Range:	1.5,4.5,9,18 m
Sensitivity:	0.1% of range
Length:	Unlimited

MANUFACTURER
Geokon

COST
Refer to Manufacturer

TYPE OF MEASUREMENT
Surface settlement relative to a buried reference point.

PRINCIPLE OF OPERATION
The model 4600 system uses a mercury or anti-freeze filled coiled tube installed in a vertical drill hole filled with bentonite slurry. This model does not require fluid filled tubes buried across the dump surface but does require drilling a shallow hole (max 5 m) into the dump surface.

The model 4650 does not require the shallow hole but does use fluid filled tubes (mercury or anti-freeze) buried across the dump surface.

As settlement occurs, the displacement relative to the fixed readout location is sensed. The differences in static head are measured at the base using a vibrating wire pressure sensor.

UNIQUE ABILITIES
High sensitivity over large ranges.

TYPICAL APPLICATIONS
Dump surface settlement. Measures the vertical vector of movement.

INTERFACING
Requires special vibrating wire strain gauge reading device. Reading can be automated.

AVAILABILITY
Off the shelf.

CASE HISTORIES
Has been widely used in civil engineering applications.

COMMENTS

Provides capability of ongoing measurement of the vertical component of dump movement without interference with truck movement on the surface of the dump. The range of the instrument is consistent with the large vertical movements expected on high waste dumps.

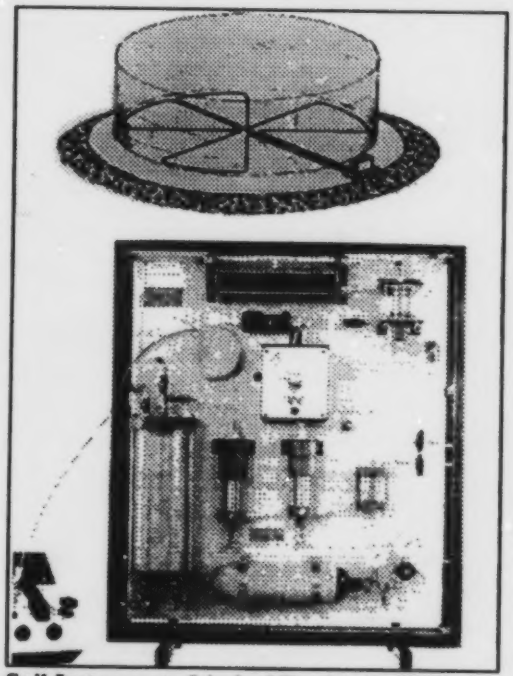
The use of the anti-freeze model is preferred due to the potential environmental impact problems of mercury. This will result in some decrease of accuracy, but the overall accuracy would still be more than adequate for dump monitoring.

The readout can be remote from the areas of dump activity. All other components are buried.

ASSESSMENT

Recommended for use where measurement of the vertical component of movement is required. Provides a useful complement to horizontal surface or buried extensometers across the dump which are capable of measuring only horizontal movement.

INSTRUMENT
DOUBLE FLUID SETTLEMENT GAUGE



Soil Instruments Limited Double Fluid Settlement Gauge

SPECIFICATIONS

Manual system:	
Length:	< 1220 m
Elevation Difference	< 6 m
Elevation Accuracy	± 10 to 38 mm
Automatic system:	
Length	< 1000 m
Elevation Difference	> 3 m
Elevation Accuracy	± 10 mm

MANUFACTURER
Soil Instruments (UK)
Solinst
RST Instruments

COST
Site specific

TYPE OF MEASUREMENT
Full profile of settlements under or within waste dump.

PRINCIPLE OF OPERATION
A continuous loop of tubing is buried along the route where settlement measurements are required. Within the tubing, there is a mercury/water interface. As the interface is driven along the tubing, the elevation profile of the tubing is obtained by measuring the fluid pressure of the mercury.

The location of the mercury is detected by electrical contacts in the tube. More sophisticated models allow mercury to bleed into the tube to advance the interface from a free surface reservoir. The position of the interface is determined by measuring the volume of water produced at the end of the tube, and the pressure gives the relative settlement at the location of the interface.

UNIQUE ABILITIES
Capable of long term accurate measurements of settlement over long distances.

TYPICAL APPLICATIONS
Used frequently in embankment dams and fill sites.

INTERFACING
Capable of data acquisition system interfacing.

AVAILABILITY
Readily available from suppliers.

CASE HISTORIES

Has been used successfully at Tarbela Dam over distances of 1220 m.

LP3 5652INST.D23

COMMENTS

Manual and portable operated systems are available. Simple system. Note the use of mercury which has potential environmental implications.

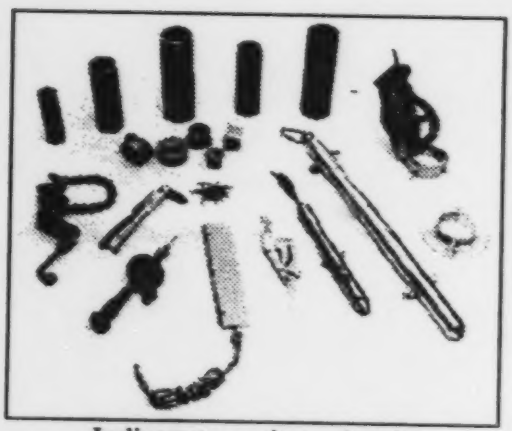
ASSESSMENT

Good for accurate monitoring of settlement profile beneath a dump or to obtain the vertical movement of the surface of the dump over wide areas. Precision is dependent on elevation differences in the system, length of tubing and expertise of the operator. May be worth consideration to obtain the vertical movement vector.

INSTRUMENT

BOREHOLE CASING INCLINOMETER

SINCO
Geokon - GK6500
Solinst - MkIV



Inclinometer casing and tools

SPECIFICATIONS

Variety of casings from different manufacturers typically ranging up to approximately 75 mm diameter.

MANUFACTURERS

Part or all of inclinometer systems:
Sinco
Geokon
Solinst Canada Ltd
RST and others

COST

Varies with manufacturer.
Typical ranges are $2000 to $10,000 for readout system and $20 to $30/m for casing. Note that most geotechnical consultants have readout systems.

TYPE OF MEASUREMENT

Measurement of deflection of borehole casing to detect lateral movement.

PRINCIPLE OF OPERATION

A probe containing gravity force tilt sensors, or servo accelerometers, is lowered through an inclinometer casing. The orientation of the probe is determined by the onboard measuring devices. Integration of successive measurements of probe orientation over depth provides the deflection of the casing over its length.

UNIQUE ABILITIES

Very sensitive system.

TYPICAL APPLICATIONS

Detection of movement at depth.

INTERFACING

Can be read automatically with automated mechanical devices. (Pulserts, Edmonton)

AVAILABILITY

Universal, off the shelf

CASE HISTORIES

Widely used instrument in civil engineering applications and in mining (Syncrude).

COMMENTS

Requires a drill hole for installation.

Very sensitive system widely used in geotechnical engineering. The casing would typically be incapable of following the large deformations resulting from typical dump movements before failure.

The conventional system does not handle interfacing to remote data acquisitions systems, although there have been recent developments in this area (see above).

Plastic tubing is usually more durable than aluminium in aggressive groundwater.

There are a wide variety of accessory systems available for data reduction and collection.

ASSESSMENT

Use of this system for dump monitoring is not generally recommended due to the inability of the casing to follow the typically large deformations that result from dump movements which are often much larger than in other embankment type structures.

On exception to this is that the system might be useful for monitoring movement of comparatively low dumps over sensitive soils (for example, collapsing soils).

INSTRUMENT

OPTICAL FIBRE FIXED INCLINOMETER

Syncrude Canada Limited

SPECIFICATIONS

Standard communications grade optical fiber is used to construct a light guide which is grouted into a borehole.

MANUFACTURER

Newport makes optical fiber
Others

COST

Cost of the fiber is low however the cost of monitoring instrumentation (light time domain reflectometry) is expected to be high.

TYPE OF MEASUREMENT

Measurement of deformation of the optical fiber.

PRINCIPLE OF OPERATION

Optical time domain reflectometry techniques employing short pulses of light are used to detect curvature, and with strain sensitive fiber, compressive and tensile strains. Light is scattered when the pulse passes a deformation in the fiber and the magnitude of the reflected pulse and time delay before its return describe the degree of curvature of the fiber and its location. The amount of light lost in the cable is a measure of its total deformation.

UNIQUE ABILITIES

Measures deformation and strain over very long gauge lengths (5 km). Can be used to locate areas of localised strain along the fiber.

TYPICAL APPLICATIONS

Being developed as an alternative to the use of Slope Indicator casing at Syncrude. When developed, may provide a relatively cheap method of measuring both deformation in a dump using a borehole as well as settlement of the foundation or the surface of the dump.

INTERFACING

No off the shelf equipment available yet but in principle could be interfaced with data acquisition.

AVAILABILITY

Under development.

CASE HISTORIES

Reported use of fiber optic monitoring along pipelines in Alaska, and in naval and military applications. Use of optical fiber as strain gauges is largely experimental.

COMMENTS

Very convenient technology to replace inclinometers when fully developed. Appears to be promising and should be followed.

ASSESSMENT

Not currently available, but worth watching.

INSTRUMENTS

FIXED BOREHOLE INCLINOMETERS

Syncrude Canada Ltd, Edmonton Research Center

Applied Geomechanics Electrolytic tilt cell

SPECIFICATIONS

Measurement to the accuracy of standard inclinometer systems. Uses standard electrolytic bubble sensors, therefore accuracy is as good as the sensors.

MANUFACTURER

None, system under development.

TYPE OF MEASUREMENT

Measures continuous profile of horizontal displacements over the depth of a borehole.

PRINCIPLE OF OPERATION

Dual axis electrolytic bubble sensors, similar to those used in electrolytic tiltmeters, are connected to short rods at regular close intervals and to a four wire power and signal cable. The bubble string is then grouted into an inclinometer borehole. A computerised data acquisition system can interrogate each sensor in succession, and the results are integrated like conventional inclinometer readings to describe the location of the tube.

UNIQUE ABILITIES

Automated and rapid inclinometer reading. Solves the problem of multiple wires required for multiple fixed downhole inclinometers, Also, likely much cheaper than use of multiple servo-accelerometer fixed inclinometers.

TYPICAL APPLICATIONS

Measurement of slope stability and ground movement.

INTERFACING

Through specialised data acquisition system to any computerised network.

AVAILABILITY

In development at Syncrude Canada Ltd.

CASE HISTORIES

Feasibility studies for monitoring highwall stability are underway at the University of Alberta and at Syncrude Canada Ltd., with reports due in 1991.

A similar instrument has reportedly been used in Australia (Hanna,1985). The instruments differ only in that the earlier Australian version had four individual wires leading to each sensor. Micro-circuitry now allows each sensor to be interrogated along a common bus. The earlier version met with limited success due to the restricted number of sensors that could be wired down one borehole.

COMMENTS

Offers cost effective replacement to conventional inclinometer systems which must be operated manually, or at least electro-mechanically. The manufacture of cheap electronic components makes this approach to sensing more and more attractive.

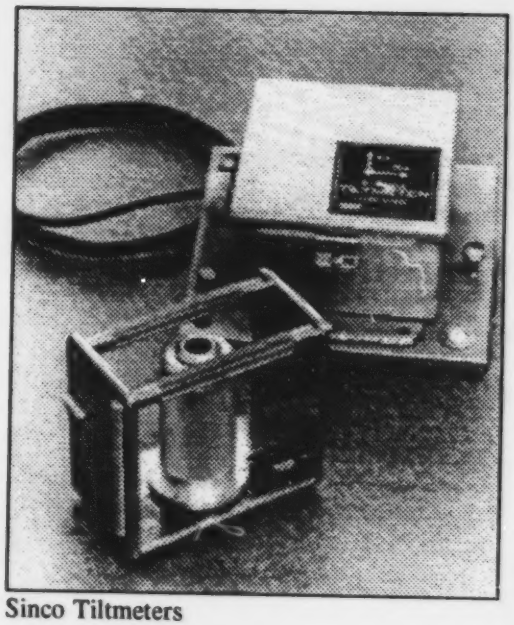
ASSESSMENT

May provide useful technology at a later date. Note that a borehole is required and that in a dump, disturbance to the instrument might occur as a result of extreme settlement of the dump. Likely less sensitive to dump movements than slope indicator casing with a moving sensor due to the longer gauge lengths of the permanently fixed instruments. Recommended for future evaluation.

INSTRUMENT

SURFACE INCLINOMETER

Sinco - Digitilt
Terra Tilt Model TT-1000 Series



Sinco Tiltmeters

SPECIFICATIONS
Range: 30° from vertical
Sensitivity: 1:10000 (10 sec of arc)
Power: Self contained 6 V
Weight: 5 pounds

MANUFACTURER
Sinco
Terra Technology

COST
Approx $5,000 (Sinco portable system)

TYPE OF MEASUREMENT
Measures angular displacement with respect to gravity.

PRINCIPLE OF OPERATION
Employs a closed-loop, force-balanced servo-accelerometer which senses changes in the tilt of the reference plate. Reference plates are secured in position. On a dump, the plates would be located on some fixed object such as a block of concrete. A fixed version of the instrument is also available both from Sinco and from Terra Technology.

UNIQUE ABILITIES
Relatively inexpensive equipment for sensitivity of measurement.

TYPICAL APPLICATIONS
Monitoring ground and structural movement.

INTERFACING
Digital display, readings can be automated.

AVAILABILITY
Off the shelf.

CASE HISTORIES
Many.

COMMENTS
Useful only where tilting movements are occurring.

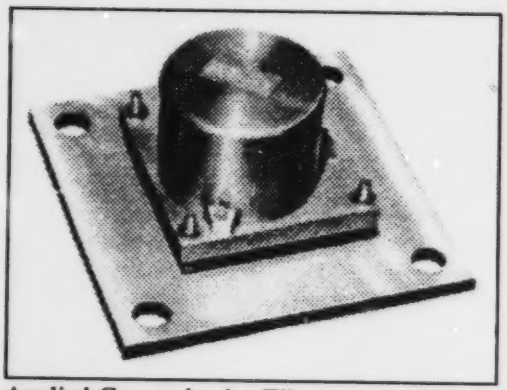
ASSESSMENT

Tilting movements are a sensitive indication of movement for certain types of failure modes in soil and rock investigations. Only useful for a few types of dump failure. Not generally recommended.

INSTRUMENTS

ELECTROLYTIC SURFACE TILTMETERS

Applied Geomechanics - Series 500, 700, 800



Applied Geomechanics Tiltmeter

SPECIFICATIONS

Angular ranges:	±0.5, ±3, ±20, ±60°
Resolution:	0.05 → 4 degrees per volt
Power:	11 → 15 VDC, 6 Ma
Operating Temperature:	-25 → 70°C
Weight:	26 g to 20 kg models

MANUFACTURER
Applied Geomechanics, Inc.

COST
Cheap, costs vary mainly with ruggedness of required housing.

TYPE OF MEASUREMENT
Measures angular displacement.

PRINCIPLE OF OPERATION
The tiltmeter consists of an electrolytic cell which incorporates several electrodes and a bubble. The cell enclosure has a spherical cap, and measurement of change of vertical orientation of the cell is made by detecting changes in impedance between the electrodes through the electrolyte.

UNIQUE ABILITIES
Gives a constant measure of angular orientation with easy connection to data acquisition.

TYPICAL APPLICATIONS
Measurement of ground and structural tilting movement.

INTERFACING
Applied Geomechanics provide their own range of data loggers and software for data reduction. The data loggers are adaptable to telemetry.

AVAILABILITY
Off the shelf from Applied Geomechanics, Inc.

CASE HISTORIES
Many

COMMENTS
See application of electrolytic bubble sensors to fixed inclinometer systems.

ASSESSMENT
Less expensive alternative than servo accelerometer tiltmeters for fixed use. Tilting movements are generally a sensitive indiction of

movement for certain types of failure modes. Similar equipment to this instrument could be located in boreholes or on the surface of the dump. In a borehole application, the unit would be much less sensitive to borehole disturbance than a standard slope indicator casing.

INSTRUMENT

COAXIAL CABLE SHEAR DETECTOR

SPECIFICATIONS
Sensor is standard coaxial cable: a solid core surrounded by a dielectric material, which is surrounded by a spun outer conductor. The conductors are typically made of copper or aluminium.

MANUFACTURER
Suppliers of cable.

COST
Coaxial cable costs less than $2 per foot. The cost of a time-domain reflectometry unit is in the order of $15,000. These units are available for rental.

TYPE OF MEASUREMENT
Detection of movement zones in ground.

PRINCIPLE OF OPERATION
Zones of movement are found by measuring changes in impedance in the coaxial cable where it has been crushed or bent. Metal time domain reflectometry uses ultra fast pulses to determine the location and magnitude of changes in impedance caused by changes in the cross-sectional geometry of the cable.

UNIQUE ABILITIES
Down-hole movement detection, and movement magnitude by use of refined technology.

TYPICAL APPLICATIONS
Down hole movement detection

INTERFACING
Metal time domain reflectometry measurement instruments are specialised. No off the shelf interfacing is known of.

AVAILABILITY
Uses off the shelf components.

CASE HISTORIES
Similar technology has been used in underground mining for several years to identify the location of caving zones and has also been applied to surface work at Syncrude. The TDR unit was originally developed for servicing cables on large aircraft.

COMMENTS
Syncrude Canada Ltd. are experimenting with the technology, trying to obtain direct correlation between signal response and movement magnitude.

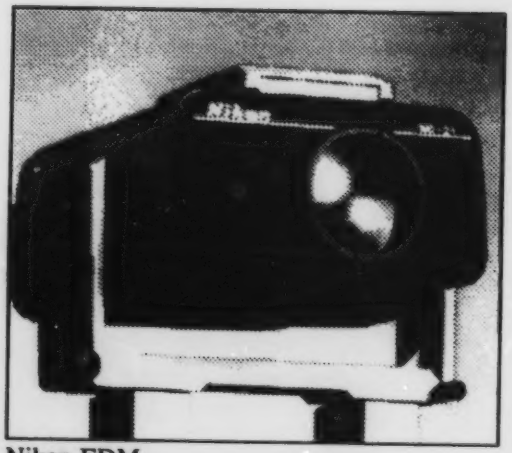
ASSESSMENT

This technology suffers from a lack of sensitivity in current versions and would not be suitable for general use in dump monitoring. If boreholes are available, it can be used to determine the depth to a shear surface.

SURVEYING

ELECTRONIC DISTANCE MEASUREMENT

Geodimeter
Wild
Nikon
Others



Nikon EDM

SPECIFICATIONS

Can be mounted as a single instrument or as part of a survey station. EDM devices are available both as total station instruments as well as separate units to be used in conjunction with a separate theodolite.

Typical accuracies:	± 5 mm ± 1 ppm.
Range:	up to 25 km.

MANUFACTURER

Geodimeter
Wild
Nikon
Others

COST

$6000 to >$50,000

TYPE OF MEASUREMENT

Linear distance measurement between a target and the instrument. Usually combined with angular measurement using a theodolite to provide X,Y,Z coordinates.

PRINCIPLE OF OPERATION

The instrument reflects frequency modulated radiation, either infrared or laser light, off a target. The time shift between the emitted and returning light gives distance to the reflector. Correction for barometric pressure and temperature conditions along the line of sight are required.

UNIQUE ABILITIES

Measures distances along line of sight paths.

TYPICAL APPLICATIONS

Widely used for monitoring of movement of pit walls and other surveying applications.

INTERFACING

Via serial port to almost any digital recording device or computer. Automatic units are now becoming available but currently have a high cost.

AVAILABILITY

Off the shelf.

CASE HISTORIES

Widely used in most mines.

COMMENTS

As with any monitoring device, correct application is required. Some instruments have proven to be overly sensitive to the harsh mine environment and are prone to cycle skipping. Use of a 1 or 2 second theodolite is required (depending on distance) to provide angular measurements with comparable accuracy to the distance measurements. Reduction of the readings using statistical methods may provide a more accurate estimate of the accuracy of the system.

There are now relatively inexpensive (±$100) prism reflectors available which reduces the cost of losing the reflectors.

Plotting of the readings as total movement vs. time and as apparent location of the station over time will assist in estimating the accuracy of the system and will reduce the number of false alarms.

The main problem with the system is the amount of time required for personnel to read the targets making continuous monitoring difficult and expensive. Servo-driven theodolites such as the Geodimeter 500 series are available which go partway to solving these problems, but the cost will have to come down a lot before they are suitable for routine dump monitoring, particularly if sight lines require the use of several units.

A major advantage of the EDM system is that the full movement vector is measured which provides a much better indication of the total movement than systems, such as the wireline extensometer, which read only a component of the total movement. Also, total movement can be measured over a period of time. See additional comments on EDM methods in the text.

ASSESSMENT

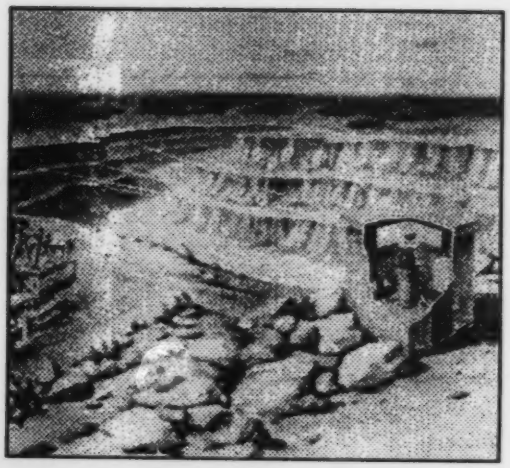
Recommended for use on dump monitoring. At the minimum, wireline extensometer bases should be equipped with prisms so that their movement may be monitored. Additional measurements on the dump, even if not continuous, will provide the full movement vector which will be of assistance in interpreting the other instrumentation installed on the dump crest.

LP5 5652SURV.D54

SURVEYING

SURVEYING ROBOT (Automatic EDM)

Geodimeter - 140SMS
Leica - DI2002



SPECIFICATIONS

Power:	24 VDC, 60 Watts
Range:	5,500 m
Accuracy: . . .	5 mm ± 5 ppm, 7" of arc
Measurement time:	1 → 5 min
Operating temperature:	0 → 50°C

MANUFACTURER

Geodimeter
Leica

COST

Approx.	$100,000

TYPE OF MEASUREMENT

An automatic surveying system for measuring angles and distances to a number of targets fitted with reflecting prisms.

PRINCIPLE OF OPERATION

A total station theodolite, fitted with servo motor circle drives, is controlled by a micro-computer to locate and measure the relative position of reflective targets. The target is located by searching its last known position for a reflection. During the search the greatest intensity of the reflected signal is taken to be the new direction to the target and the new distance is measured using EDM technology.

UNIQUE ABILITIES

Unmanned surveying to high precision.

TYPICAL APPLICATIONS

Monitoring of open pit mine slopes.

INTERFACING

Data acquisition systems via the controlling computer.

AVAILABILITY

From Geodimeter.

CASE HISTORIES

Noranda Mines.
Quebec Cartier Mine.
Reported Installations in Sweden.

COMMENTS

Sierra Misco have developed a software interface to the Geodimeter control software (see data sheet).

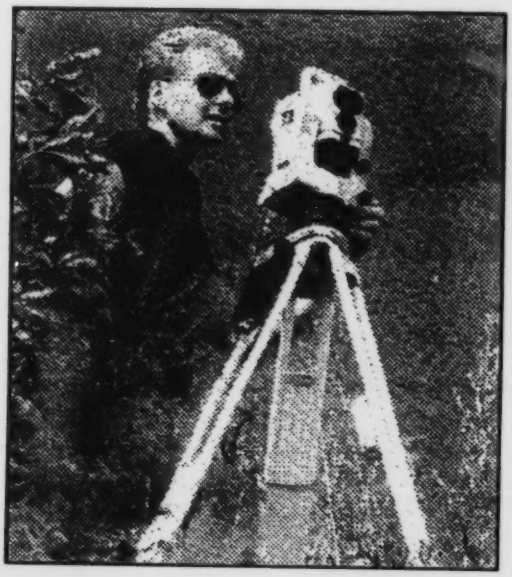
ASSESSMENT

Targets have to be placed and maintained upon critical parts of the dump face and crest. This technology may offer significant advantages in the future for use in labour intensive monitoring, particularly for frequent reading of targets which are moving, and for rapid automated reporting of results. At present the cost is high.

SURVEYING

SEMI-AUTOMATED THEODOLITE

Geodimeter - 400 and 500 Series



SPECIFICATIONS

Power:	6 Watts, 0.5 A
Range:	0.2 to 7,000 m
Accuracy:	5 mm ± 5 ppm, 2" of arc
Measurement time:	0.4 → 7 s
Operating temperature:	-20 → 50°C

MANUFACTURER
Geodimeter

COST
Series 500 with servo-drive and large datapack approx. $20,000→$35,000

Series 400 one man theodolites approx. $60,000

TYPE OF MEASUREMENT
Semi-automated total station surveying. Geodimeter also makes one man theodolites.

PRINCIPLE OF OPERATION
The instrument seeks targets by turning the circles to point the telescope at their last known location. It takes readings of their new location once the instrument has been centered by its operator.

UNIQUE ABILITIES
Automatic pointing to target zones greatly increases the speed of the surveying operation. Has built-in two way communication beam system to allow instrument and target sites to communicate.

TYPICAL APPLICATIONS
Any surveying where repeated location of multiple distant targets is required. Typical of most monitoring operations.

INTERFACING
Via GEO I/O data pack to any computer.

AVAILABILITY
From Geodimeter.

COMMENTS
This equipment is a significant improvement over manual surveying. The ease and speed at which targets can be measured and the data stored makes routine monitoring more effective and reliable.

ASSESSMENT
It would be preferable to use fully automated equipment to allow unattended operation of the data gathering operation. The equipment is considerably cheaper than the fully auto-

mated version, and may be moved to several jobs in sequence.

This type of equipment is quite new and will likely be available from several manufacturers in the near future. The only advantage is that the speed of monitoring is increased since an operator is still required.

GLOBAL POSITIONING SYSTEM

Trimble Navigation - Geodetic Surveyor IIP and Geodisist P
Magellan
Aztec

Trimble GPS Surveying Equipment

SPECIFICATIONS

Power:	10.5 → 35 VDC, 11 Watts
Operating Temperature:	-20 → 55°C
Size:	30 x 35 x 13 cm
Weight:	11.7 kg
Accuracy:	Up to 5 mm ± 1 ppm horizontal
	10 mm ± 1 ppm vertical

MANUFACTURER
Trimble Navigation
Magellan
Aztec

COST
Varies with required accuracy:

In general	±20 m: $5,000
	±2-5 m: $35,000
	±5 mm: $100,000

TYPE OF MEASUREMENT
Static survey of location of single or multiple antennae.

PRINCIPLE OF OPERATION
The satellite antenna receives 1023 bit coded signals from eight orbiting satellites. The GPS receiver uses the best four to determine the antenna's location by calculating signal cycle offsets. The location of the orbiting satellites is known and communicated to the receiving station at intervals. Accuracy in GPS geodesy is obtained by using multiple satellites for reference and averaging repeating readings.

For maximum accuracy the use of differential GPS is recommended. Two reference receivers are situated at the ends of a baseline up to several kilometers long. The receivers are stationed for a long period of time and thus determine the location of the baseline ends to good accuracy. Once the location of the baseline is known, the reference receivers can calculate signal corrections and broadcast a correction signal and their own location signal to local field receivers. This allows the filed units to operate to high accuracy using only short reading times.

For a typical mine, only one baseline would be required to service all areas of the mine. The field receivers are relatively inexpensive compared to the reference receivers.

UNIQUE ABILITIES
Uses orbiting reference points to calculate position on the earth's surface. Very fast measurement. The use of ground reference stations is cost effective in increasing accuracy

INTERFACING
RS-232 ports for data transmission. Dual power inputs.

AVAILABILITY
Off the shelf from manufacturers.

CASE HISTORIES
There are installations for embankment monitoring in the US (US Army Corps of Engineers) and Canada (BC Hydro).

COMMENTS
Not all global position fixing satellites have been launched due to delays in the space shuttle program. Coverage is good from 55°N to 55°S of the equator. The use of reference stations removes some of the reliance on the satellites.

Accuracy is affected by clock precision, existence of reflected signals, relative position of reference satellites, and artificial errors introduced by the American military at will. However, the use of a permanently located reference stations reduces error introduced by all causes by providing a known reference point.

The Canadian government has proposed to install a set of four publicly maintained ground stations in northern regions to increase regional location accuracies.

ASSESSMENT
This equipment will be widely used in the future. At present the cost is relatively high, but the cost of the receivers, particularly the field receivers is dropping very rapidly. The technology offers a number of advantages including less dependence on weather, data acquisition capability and accuracy. This technology should be watched in the future.

7.2 Pore Pressure

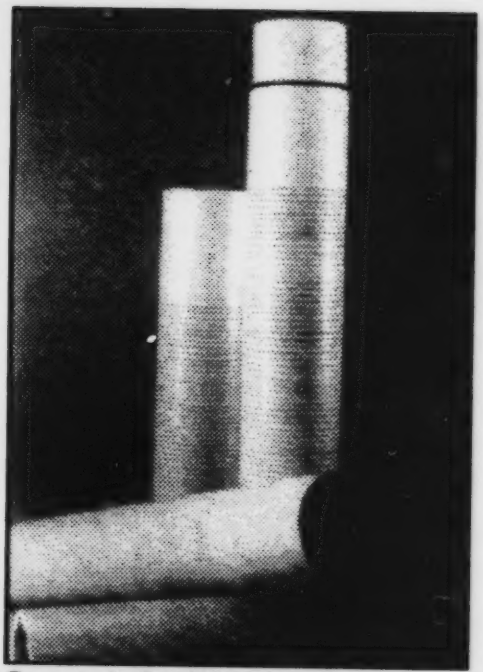
The methods of pore pressure measurement are based on methods used in geotechnical use. The equipment is well proved, but the method of installation may require deep boreholes or require that the piezometers be placed in holes in the foundation in front of the advancing dump. Either method is more difficult than conventional installations in civil engineering projects. However, the data acquired is vital to proper understanding of dump behaviour as discussed elsewhere in this report.

Data sheets included in this section are as follows:

Data Sheet	Page
Standpipe piezometer (Casagrande type)	7-39
Pneumatic piezometer	7-41
Strain gauge piezometer	7-43
Silicon Diaphragm Pore Pressure Transducer	7-45
Vibrating wire piezometer	7-47
Twin tube hydraulic piezometers	7-49
Multipoint systems (Fixed piezometers)	7-51
MP Piezometer system (moveable probe)	7-53

PIEZOMETER

STANDPIPE (Casagrande)



Casagrande Standpipe Piezometer

SPECIFICATIONS (Typical)

Maximum O.D.:	1.32"(3.35 cm)
Length:	13.95"(35.4 cm)
Filter area:	37.69 in^2 (243 cm^2)
Body material:	1" PVC
Filter Pore Diameter:	70 micron

MANUFACTURER

RST Instruments Ltd.
Carlson/RST Instruments INC.
RICE Engineering
Most geotechnical instrumentation companies.

COST

Basic tip $12 to $16
Additional standpipe required.

TYPE OF MEASUREMENT

Water pressure where time lag and high displacement are not crucial.

PRINCIPLE OF OPERATION

Casagrande type piezometer tip consisting of a slotted PVC body enclosing and protecting a porous plastic filter element is installed in a drilled hole surrounded by a filter zone. The unit is sealed into the formation. The depth of the water table is measured using a "dip meter" which is lowered inside the standpipe until it detects the surface of the water.

UNIQUE ABILITIES

Can be used for sampling of water quality.

TYPICAL APPLICATIONS

Monitoring porewater pressures in high permeability materials. Sampling of groundwater and leachate extraction.

INTERFACING

A conventional fast acting piezometer system can be incorporated to allow remote reading.

AVAILABILITY

Readily available from suppliers

CASE HISTORIES

Commonly used in geotechnical engineering.

COMMENTS

Unsealed standpipes should not be used due to major errors caused by cross-connections between aquifers.

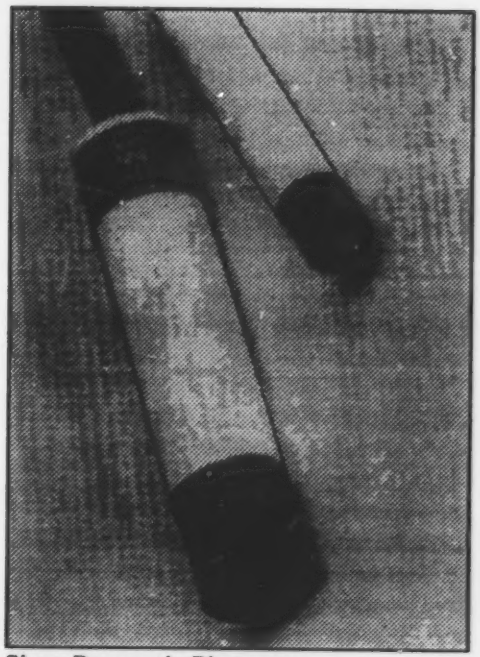
Simple direct measurements of water table elevation. Suitable only for reasonably permeable material. Can be nested to two or three units to measure different levels in one borehole using effective seals between each tip. An older system of piezometric measurement.

ASSESSMENT

Not generally recommended due to problems with low permeability materials. Some of the standpipes available are refinements of the open standpipes and have lower volume displacements (smaller diameter) than an open standpipe but are still not suitable for installation in low permeability materials.

Samples can be obtained and permeability tests can be undertaken in suitable materials. This is the only time that these units should be installed. Manual monitoring is generally used.

PIEZOMETER
PNEUMATIC
Pore Pressure Measurement



Sinco Pneumatic Piezometer

SPECIFICATIONS (typical)

Maximum O.D.:	32 mm
Filter pore size:	70 microns
Sensitivity:	
0-1000 Kpa	0.5 kPa
0-2000 kPa	1.0 kPa

MANUFACTURER

RST Instruments Ltd.
Roctest Ltee Ltd.
Sinco Ltd.
Soil Instruments Ltd. (UK)
Terra Technology Corp.

COST

Basic unit	$80 to $140
Tubing	$1.50/metre
Readout equipment	$2,000 to $3,500

Readout equipment from one manufacturer is often compatible with another manufacturer's product, but this should be checked first.

TYPE OF MEASUREMENT

Pore water pressure on a diaphragm in a piezometer tip sealed in the formation.

PRINCIPLE OF OPERATION

A flexible diaphragm in the tip is deformed by external fluid pressures. Gas pressure is applied to the inside of the diaphragm and the magnitude of the equalizing pressure is measured at a gauge at the surface. Different types of equipment read pressure in the gas supply tube or in a static return tube.

UNIQUE ABILITIES

Basic fast acting piezometer which is applicable to a wide range of situations. Widely used. In western Canada, RST and Sinco units are the most widely specified.

TYPICAL APPLICATIONS

Monitoring pore water pressures in dams, embankments, fills and waste dumps.

INTERFACING

Can be adapted to remote measurement, but requires special equipment.

AVAILABILITY

Readily available from suppliers.

CASE HISTORIES

Commonly used in geotechnical engineering.

COMMENTS

Requires care to avoid damage to leads which can be difficult to detect. Interfacing with data acquisition is more difficult, but interfacing units are available.

Can be used to measure negative pore water pressures. Adaptable to horizontal installation below dumps using a readout station at a suitable location. Low volumetric displacement but there is still lag-time in reading if filter material is placed around the unit.

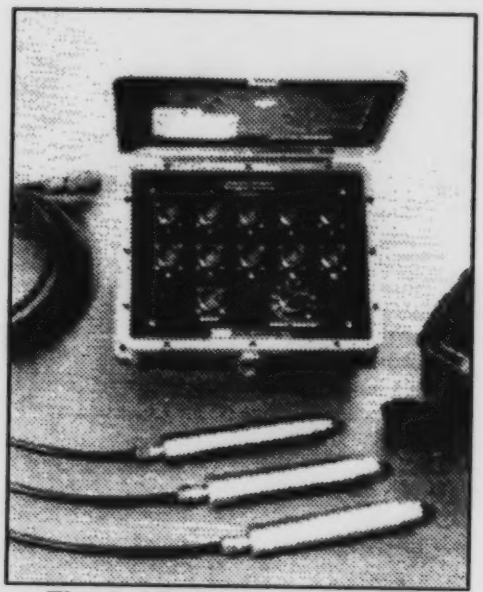
Long tubing runs outside the bore hole should be avoided.

Like any instrument, requires knowledgable personnel to avoid misleading or incorrect results.

ASSESSMENT

Widely used and recommended for use.

STRAIN GAUGE PIEZOMETER



Electrical Resistance Strain Gauge Pressure Transducer

SPECIFICATIONS (typical)

Maximum O.D.:	34 mm
Length:	254 mm
Input Voltage:	5-18 VDC

MANUFACTURER

RST Instruments Ltd.
Sinco
Terra Technology
Geokon
Others

COST

Basic Unit	$500 to $650
Leads	$1.50 /foot
Readout unit	$2,500

TYPE OF MEASUREMENT

Pore water pressure.

PRINCIPLE OF OPERATION

A four arm strain gauge bridge, bonded onto the surface of an active diaphragm, measures strains on the diaphragm. The basic sensor is built into a fully encapsulated solid state transducer. The gauges are calibrated to allow conversion of strain to equivalent pressure on the diaphragm.

UNIQUE ABILITIES

Can also be used to measure temperature of fluid. Can be used to measure negative pore water pressure.

TYPICAL APPLICATIONS

Monitoring pore water pressures in dams, embankments, waste dumps.

INTERFACING

Automatic data acquisition systems are available for remote monitoring.

AVAILABILITY

Readily available.

CASE HISTORIES

Commonly used in geotechnical engineering.

COMMENTS

Disadvantages are possibly lower long term reliability, higher cost, and possible zero drift errors. Change in total stress acting on the piezometer tip can cause errors with some units. This is the only system which can be considered for measurement of dynamic pressure change.

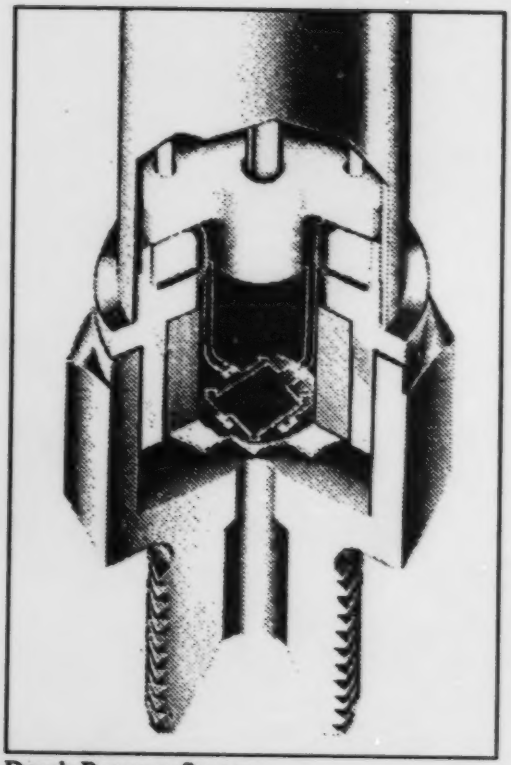
ASSESSMENT

Simple, robust instruments for general use. Recommended for dump monitoring. Easier to interface with data acquisition units than other types of piezometer.

INSTRUMENT

SILICON DIAPHRAGM PORE PRESSURE TRANSDUCER

Druck Limited - PDCR, PCX



Druck Pressure Sensor

SPECIFICATIONS

Power:	9 → 30 VDC, 20 mA
Pressure Range:	1 → 10000 psi
Resolution:	0.005% of full scale

MANUFACTURER
Druck Incorporated

COST
Approximately $1000

TYPE OF MEASUREMENT
Fluid pressure and pore pressure.

PRINCIPLE OF OPERATION
The transducer's sensing element is made by incorporating a four arm strain gauge bridge into the surface of a single silicon crystal. The sensitivity of the transducer is altered by changing the diameter and thickness of the crystal.

UNIQUE ABILITIES
Free from hysteresis, and gives good outputs at low strain levels. Extremely accurate and very high shock resistance.

TYPICAL APPLICATIONS
High quality pore pressure monitoring especially under extreme conditions of shock, temperature or at low heads where unusually high accuracy is required.

INTERFACING
Druck supply their own range of logging equipment, their gauges can be read using conventional logging systems.

AVAILABILITY
Off the shelf

CASE HISTORIES
Used by HBT for some critical applications outside the mining industry.

COMMENTS
Very sensitive, reliable gauges. Can be housed in many casings for hostile environments. These are the "Rolls Royce" of piezometers. For most jobs, they are of better quality than what is required.

ASSESSMENT

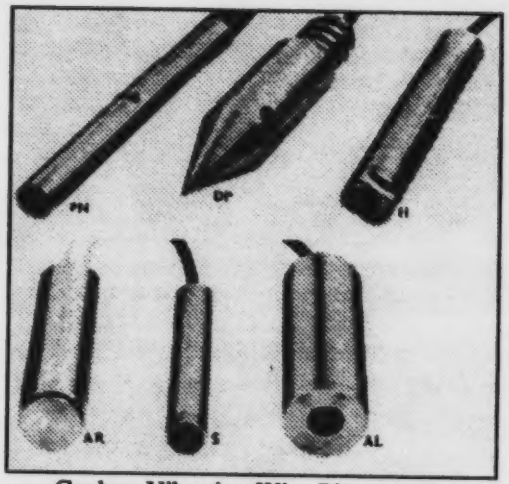
The Druck units are of a higher quality and sensitivity than is needed for most dump monitoring situations and are not recommended due to cost. They are very stable, very rugged and very expensive. They are the only units which can reliably measure very small heads and can differentiate between low head and no head.

If extreme conditions or requirements necessitate the use of these instruments, the cost is justified. Otherwise, there are cheaper alternatives that will fulfil most needs.

INSTRUMENTS

VIBRATING WIRE PRESSURE TRANSDUCERS

Geokon - Solinst 4500
Roctest PWS, PWP



Geokon Vibrating Wire Piezometers and Pressure Transducers

SPECIFICATIONS

Standard range:	5, 10, 25, 50, 100, 250, 500, 1000, 5000 psi
Resolution:	0.025% Full scale
Accuracy:	0.05% full scale
Operating Temp:	-29 → 65 °C
Displacement:	0.001 cm^3 at FS
Filter:	50 micron sintered screen

SUPPLIERS

Geokon
Roctest
Solinst
RS Technical
Sinco

COST

$500 to $650

TYPE OF MEASUREMENT

Pore pressure.

PRINCIPLE OF OPERATION

Change of pressure flexes a diagram in an internal cavity of the gauge. The deflection of the diagram is measured by means of a vibrating wire strain gauge.

UNIQUE ABILITIES

Measures fluid pressure (head). Can be installed at great distances from the measuring unit due to the stability of the frequency output. Can be installed horizontally in fills, can be used to measure temperature of fluids, and can be used to measure negative pore water pressure.

TYPICAL APPLICATIONS

Measuring fluid head in boreholes to provide free surface elevation. Suited for installation in dams, embankments, and waste dumps.

INTERFACING

Must be read by a special device. Reading can be automated for remote monitoring.

AVAILABILITY

Readily available off the shelf.

CASE HISTORIES

Many, the instrument is commonly used in geotechnical engineering.

COMMENTS

Normally very fast response to changes in pressure (normally 1/100 s) but the reading rate is somewhat slower limiting use of the instrument for monitoring of dynamic pore pressure changes. Does not have as good a dynamic response as the strain gauge type of

instruments. The FM data signal can be reliably transmitted for long distances without calibration or signal degradation problems.

ASSESSMENT

Suitable and recommended for use. The main advantage of the equipment is in the distance that the FM signal can be transmitted without degradation or calibration changes.

PIEZOMETER

TWIN-TUBE HYDRAULIC PIEZOMETERS

Bishop Twin-tube Piezometer

SPECIFICATIONS

High air entry ceramic element retained with various fittings to allow two tubes to connect to surface measuring unit.

Typical size: length 185, diameter 52 mm.

MANUFACTURER

Soil Instruments Ltd. (UK)
R.S.T.Instruments Ltd. (Canada)
Carlson/R.S.T. Instruments (USA)

COST

Basic unit	$140 to $160
Tubing	$1.50/metre
Manual read-out device	$500
Transducer reading device	$1500

TYPE OF MEASUREMENT

Water pressure in the ground where longevity is required.

PRINCIPLE OF OPERATION

A porous filter element is connected to two plastic tubes. The tubes are filled with de-aired water which allows measurement of heads to within certain limits relative to the head difference between the monitoring station and the piezometer.

UNIQUE ABILITIES

The tubes from the piezometer tip can be distributed horizontally up to 1000 metres through a fill to a suitable location for the pressure gauges. Can be used to measure negative porewater pressure.

TYPICAL APPLICATIONS

Used successfully for long term monitoring of embankment dams.

INTERFACING

Automatic data acquisition systems area available, with a scanner to allow an electrical pressure transducer to be coupled hydraulically to each piezometer in turn.

AVAILABILITY

Readily available from suppliers.

CASE HISTORIES

Commonly used in embankment dams.

COMMENTS

Can be checked after installation by constant or falling head permeability tests.

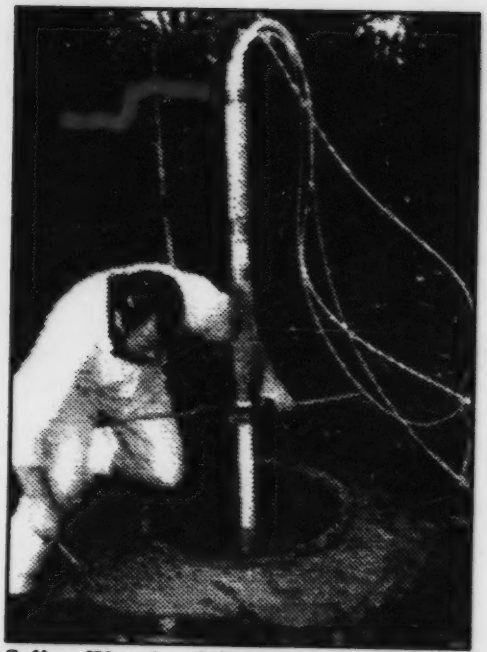
ASSESSMENT

This is old-fashioned technology which is complex to maintain in the field. Not recommended for application to dumps.

PIEZOMETER

MULTIPLE POINT SYSTEMS

Fixed Piezometers



Solinst Waterloo System

SPECIFICATIONS

Piezometers used in system are typical of standard types. Dimensions of equipment should be obtained from the supplier.

MANUFACTURER

Solinst Ltd.
(Waterloo system)

COST

Site specific. Typically less expensive than drilling multiple holes to permit the installation of several piezometers.

Typical installation:	120 m deep, 5 levels
Installed equipment	$13,000
Read-out device	$5,000

TYPE OF MEASUREMENT

Groundwater pressure at various fixed levels in a single borehole.

PRINCIPLE OF OPERATION

Several piezometers are assembled into a casing with a packer above and below each unit. The packer isolates the zone where the piezometer tip is located. Standpipes, pneumatic or vibrating wire piezometers may be used to measure the groundwater pressure.

In addition to piezometric measurements, pump or injection tests may be done and groundwater samples obtained.

UNIQUE ABILITIES

Measurement of many monitoring zones in a single borehole. Uses standard piezometers which may be more easily interfaced with data acquisition.

TYPICAL APPLICATIONS

Monitoring pore water pressure at various levels in a single borehole within mines, dams, embankments and waste dumps.

INTERFACING

Can be automated to read from multiple depths in each borehole.

AVAILABILITY

Readily available from suppliers.

CASE HISTORIES

Has been used in installations in geotechnical applications.

COMMENTS

Suited to deep boreholes where multi-level groundwater pressures are required. Several piezometers can be packaged within a length of casing to create a multipoint unit to be inserted in a borehole and backfilled with grout.

Installation of pumping or sampling ports is also possible.

The sealing into the formation using relatively short packers requires great care and knowledge of the formation to prevent leakage and pressure loss around the seal.

ASSESSMENT

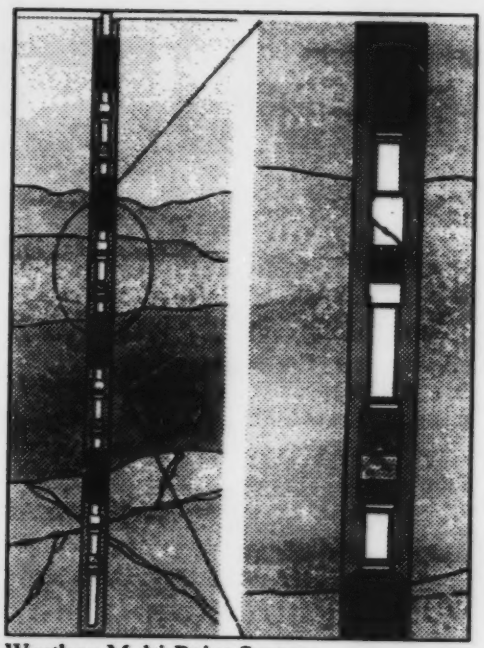
Reliable and permits direct reading of groundwater pressure at several locations using data acquisition. Less susceptible to borehole disturbance in a moving dump than the Westbay system since there is not moveable probe, however the system (especially the seals) could be damaged.

Note that there is less redundancy (and often cost) in using a single borehole than a multiple borehole installation. Recommended for dump monitoring only where multiple measurements in a single hole are required. See caution above regarding possible problems of sealing.

PIEZOMETER

MULTIPLE POINT SYSTEMS

Movable probes



Westbay Multi-Point System

SPECIFICATIONS

Vary with individual supplier.

MANUFACTURER

Westbay Instruments Inc.
Federal Institute of Technology, Zurich, Switzerland.

COST

Site specific. Typically competitive with multiple installations in several holes. Equipment requires setting and installation tools, as well as a reading device. Installation of a 120m deep casing with 5 ports in a predrilled hole costs about $12,000. The readout device, winch, a probe, and a sampler cost $70,000.

TYPE OF MEASUREMENT

Groundwater pressure at various levels in a single borehole with a movable probe which accesses different measuring ports on the installed casing. In addition, other tests such as pumping or injection tests may be available and water sampling is facilitated.

PRINCIPLE OF OPERATION

Modular multiple-level groundwater monitoring device employing a single, closed access tube with ports. The ports can incorporate a spring system to enable measurement of pore water pressure outside the casing. The measurement zones along the casing are separated using packers. For the Westbay system, the measurement is made using a pressure transducer in the probe.

UNIQUE ABILITIES

Modular design permits measurement of many monitoring zones in a single borehole up to 1500 m depth. Can use inclinometer casing but this leads to a loss of sensitivity for inclinometer use. Can be used for groundwater sampling, permeability testing and temperature measurement.

TYPICAL APPLICATIONS

Monitoring pore water pressure at various levels in a single borehole within mines, dams, embankments and waste dumps.

INTERFACING

Can be automated to read from multiple depths in each borehole using intelligent pressure probes.

AVAILABILITY

Readily available from suppliers.

CASE HISTORIES

Has been widely used for environmental applications and also for geotechnical use in critical situations.

COMMENTS

Suited to deep boreholes in difficult ground where multi-level groundwater pressures are required.

The Piezodex system from Switzerland is not widely used in North America. The Westbay system has been installed in a variety of environments.

ASSESSMENT

Not recommended for general use, but could be considered for special applications. Reliable and permits direct reading of groundwater pressure. Installation and measurement procedures are tricky. For most dump monitoring situations on active dumps, the movement that occurs would likely destroy the casing.

7.3 Stress or Pressure

The methods discussed in this section are typically based on civil engineering methods. Measurement of stress or pressure would not be required on every dump, but are very useful to correlate with pore pressures to measure the pore pressure generation in the dump foundation as a result of loading by the dump.

Data sheets included in this section are as follows:

Data Sheet	Page
Earth pressure cell	7-59
CSIRO Hollow Inclusion Gauge	7-61

INSTRUMENT

EARTH PRESSURE CELL

Geokon - 2510,3500,4800,4800EC
Solinst - III-P, VII-P
R S Technical Instruments

Geokon earth pressure cell

SPECIFICATIONS

Transducer:	Pneumatic
	Semiconductor strain gauge
	Resistance strain gauge
	Vibrating wire
Load ranges:	15 → 5000 psi
Accuracy:	0.4 → 1% of full scale
Resolution:	0.1 → 0.4 % of full scale
Readout box:	As appropriate to gauge

MANUFACTURER

Geokon
Soil Instruments Limited
RST Technical Instruments
Others

COST

Basic instrument	$500 to $600
Wire Leads	$2.00/metre

TYPE OF MEASUREMENT

In-situ total stress in one direction or pressure against structural elements.

PRINCIPLE OF OPERATION

Fluid inside a flat closed cell is brought into equilibrium with the pressure outside the cell. The fluid pressure at equilibrium is measured using standard pressure transducer mounted on a short length of tubing leading from the cell.

UNIQUE ABILITIES

Measures total uniaxial stress perpendicular to plane of instrument. A wide variety of instruments for different applications are available.

TYPICAL APPLICATIONS

For dump monitoring applications, would be of use only in research type applications and monitoring. Would not generally be required for routine monitoring. Useful in conjunction with pore pressure measurements in foundations soil to calibrate pore pressure response of foundations soils during loading.

INTERFACING

Can be read manually or connected to data acquisition system.

AVAILABILITY

Off the shelf

CASE HISTORIES

Widely used in civil engineering and in special applications in miming.

COMMENTS

Push-in cells are available which can be jacked into granular material on the end of a drill rod (Solinst VII-P).

Could be installed either in a borehole or buried in soil and covered over by dump advance.

ASSESSMENT

Not generally recommended for routine monitoring situations for dumps. May be required for special applications (eg., dump material against a bulkhead) or for research type monitoring. May be very useful in conjunction with installed piezometers in foundation soil to measure pore pressure response.

INSTRUMENT

CSIRO HOLLOW INCLUSION GAUGE

R. S. Technical Instruments Ltd

RST's CSIRO Hollow Inclusion Cell

SPECIFICATIONS

Borehole size:	38 mm or larger
Circuit:	three wire quarter bridge.
Sensitivity:	$5.0 \rightarrow 5.5 \times 10^{-5}$ mm/μV

MANUFACTURER

RST Technical Instruments Ltd.
(supplier)

COST

$700

TYPE OF MEASUREMENT

Measures the change in diameter of the borehole caused by changes in the stress field within the host rock. A knowledge of the elastic properties of the rock enables calculation of the deviatoric principle stresses in the rock on a plane orthogonal to the axis of the borehole. The change in stress is measured via a strain gauge rosette within the instrument. For use in a dump the instrument would be cemented or grouted into the borehole.

PRINCIPLE OF OPERATION

The instrument is normally epoxied into the borehole at the desired location but for this application would likely be grouted into place. Stress changes are measured by means of a strain gauge rosette and are converted into equivalent deformation of the rock.

UNIQUE ABILITIES

Monitor stress at any given location along a borehole. The design allows multiple gauges to be installed in one hole. Measures a wide range of stress changes.

TYPICAL APPLICATIONS

Measuring changes of stress in rock formations. Has been applied to the measurement of stress changes in backfill materials underground.

INTERFACING

Can be read by data logging system.

AVAILABILITY

Off the shelf.

CASE HISTORIES

Widely used for rock stress measurements.

COMMENTS

This is an unusual application of the instrument. The use of grout with different elastic properties than the dump materials may cause errors. The instrument would likely only be required for special applications.

Note that there are alternate means of making in-situ stress measurements in waste dumps. Other possible instruments to consider are flat jacks grouted in place and the USBM borehole plattened flatjack.

ASSESSMENT

Recommended only for special applications and only then with reservations. The applicaiton of the system to dumps with large particles has not been proven. There are several potential problems which might result in the instrument returning very misleading results.

7.4 Other

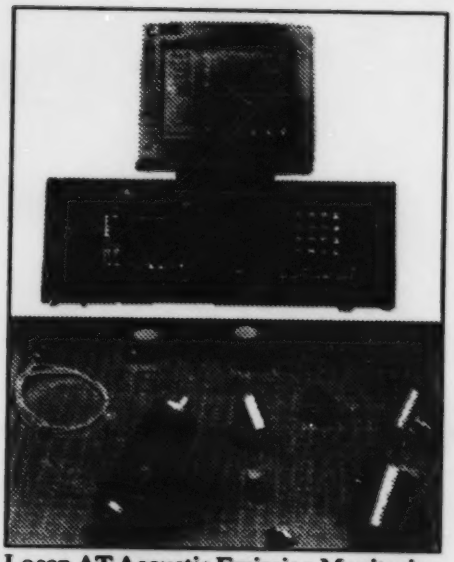
This section includes data sheets for several unconventional methods of monitoring. As noted, many of these methods are still under active development and remain to be proven for application to dump monitoring.

Data sheets included in this section are as follows:

Data Sheet	Page
Acoustic emission	7-65
Electromagnetic emission. Equipment not sufficiently developed to allow preparation of a data sheet.	
Laser range camera	7-67
Videometry	7-69
Satellite imagery	7-71
Photogrammetry	7-73

REMOTE SENSING

ACOUSTIC EMISSION DETECTOR



Locan AT Acoustic Emission Monitoring Station and Sensors

SPECIFICATIONS

AE sensor frequency response:
10 kHz to 1000 kHz
typically 50 - 250 kHz

SENSOR MANUFACTURER

AE Technology Corp. (USA)
Physical Acoustics Corp. (USA)
Newt Seismic Systems

COST

Site specific.
Approximately $1000 per sensor with automated data acquisition/transmission system. As the technology becomes more widely used the cost will decrease.

TYPE OF MEASUREMENT

Monitoring of rupture noise in stressed material. The currently available equipment measures numbers of events per unit time and warns of increased activity which could signify an impending failure..

More advanced capabilities under development include the location of the origin of events using time domain measurement, employing both homogeneous and non-homogeneous models of material properties through which the signal is transmitted. In the latter instance the transmission of various phases of the signal can be analysed to determine the origin of the event. When this capability is available using real time instead of post-processing it will be a very valuable tool.

Work in this area is underway by the Italians (Carabelli et al, 1987) and by Schlumberger (1991). Additional references are Descour and Miller (1989) and work by Vladut in Canadian mines in the late 1970's. Previous trials of this method ten years ago did not succeed due to the large amount of data that had to be processed.

PRINCIPLE OF OPERATION

A piezoelectric transducer (geophone) is used to detect acoustic signals in the ground and convert the signal to an proportional electrical signal. Frequency and duration of recorded events are an indication of movement condition in the dump.

The extension to the method referred to above requires the correlation of signals (events) and the calculation of travel times to allow the location of the event to be determined, thus allowing the location of the shear movement to be calculated in three dimensions.

UNIQUE ABILITIES
Can be incorporated into existing boreholes with metal casings, inclinometer tubes or piezometers. Can be used to predict failures.

Future developments in this technology may provide useful monitoring equipment.

TYPICAL APPLICATIONS
Monitoring behaviour of dams, embankments, waste dumps, landslides, underground openings, and civil structures.

INTERFACING
Can be adapted to automated data acquisition/transmission for remote monitoring.

AVAILABILITY
Readily available from suppliers.

CASE HISTORIES
Used more recently in landslide monitoring, dams and bridges using automated monitoring systems.

Verbal reports indicate that Schlumberger is also working on developments in this area.

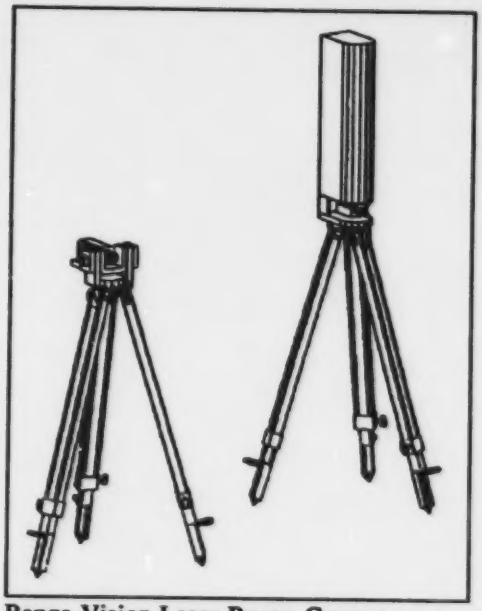
COMMENTS
Extraneous noise can be filtered out of the record. Most acoustic emissions due to rupture of materials are high frequency signals which attenuate rapidly and require wave guides or sensors close to the source.

ASSESSMENT
Simple, robust system well suited to harsh environment and remote monitoring. Site specific calibration required after installation. Presently not well enough developed to recommend. Modern computer developments offer the possibility of solving past problems with this equipment. Future developments appear to offer promise.

REMOTE SENSING

LASER RANGE CAMERA

RVSI - Rangecam - L/5



Range Vision Laser Range Camera

SPECIFICATIONS

Working range:	2 - 50 m
Resolution:	1:5000 (1 cm at 50 m)
Accuracy:	3 x resolution
Repeatability:	equal to resolution
View angle:	Vertical: 22˚
	Horizontal: 28˚
	(Field 27 m wide at 50 m)

Range: 50 m with present laser, 300 m with different laser, range is longer when ambient light levels are low (e.g. at night).

MANUFACTURER

Range Vision Inc,
Burnaby B.C. (604) 299 4455

COST

At least $50,000. Contact Manufacturer.

TYPE OF MEASUREMENT

A range camera uses projected light and a video camera to measure three dimensional surfaces. The object is described by assigning x,y,z coordinates to each pixel of its image.

PRINCIPLE OF OPERATION

The video camera and laser projector are set on a known baseline. The L/5 scans a collimated laser beam through the field of view of the video camera. A computer positions the beam, tracks the beam in the image, and performs precise triangulations to produce an array of x,y,z coordinates that describe the image.

UNIQUE ABILITIES

All data captured by the range-camera can be converted into CAD models in standard formats, and be exported to other programs. Target surfaces can be assessed for geometric regularity and orientation. Surfaces, edges, and planes can be identified.

The operating system can be programmed perform repeated inspections, change frequency and density of measurements, and sound alarms based upon measurement results.

TYPICAL APPLICATIONS

The range-camera is portable and can run unattended. Applications in mining include:

- Stockpile measurement
- At face volume computation
- Face movement detection

INTERFACING
The range-camera is controlled by a PC through a dedicated interface box. The software for controlling the camera, processing the image information, and displaying and exporting the image data is all integrated and may be adapted for specialist use.

AVAILABILITY
Range cameras with the specifications cited are available from Range Vision Inc. RVI have stated that custom configurations with greater resolution and range are technically possible though not available off the shelf.

CASE HISTORIES
None in mine monitoring. Several systems ar in use at other tasks in B.C.

COMMENTS
This equipment is at present not suited for dump monitoring due to range restrictions, but with further development, may offer a useful monitoring tool.

The optical quality and orientation of the target surface, and environmental light conditions can interfere with machine operation. Rock is generally a good reflector, and readings on clear nights are best.

Resolutions of 1:23000 have been obtained in RVI's laboratory. Accuracy can also be increased by sighting on regular objects (spheres, planes) and performing least squares adjustment on multiple readings to identify the location of the object.

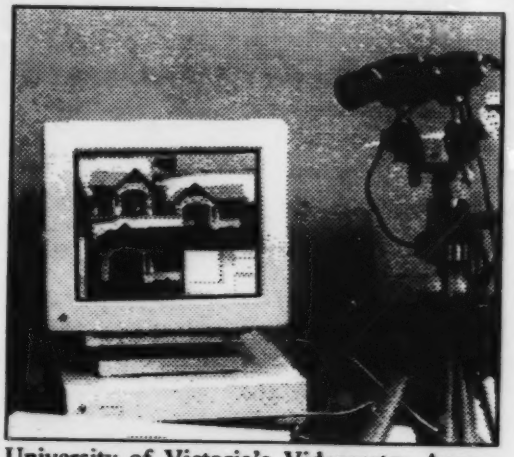
ASSESSMENT
Not currently useful technology for dump monitoring. The technology is very new at present. No long range (300 m) cameras have been built however they are technically possible.

The software control system is readily adaptable to tasks involved in monitoring mines.

This area of technology may offer useful equipment for mine monitoring in the future. See related technology under development at the University of Victoria (videometry)

LP3 5652REM.DS4

VIDEOMETRY



University of Victoria's Videometry Apparatus

SPECIFICATIONS

High resolution video cameras with known orientation upon a measured baseline. Software to control data gathering and reduction.

Attainable accuracies range from 1:1000 to 1:4000 of the scale of the image. Selective acquisition can be used to zoom in on an area of interest. Systems can scan large regions using multiple cameras. Images can be acquired at a rate of up to 30 Hz, depending upon the amount of analysis performed. Systems can operate for long durations, on a report by exception basis. Performance largely unaffected by changes in weather.

MANUFACTURER

Under development at the University of Victoria (MacLean, 1991)
EOS Systems Incorporated, Canada

COST

$30,000 to $50,000 for a complete package.

TYPE OF MEASUREMENT

Automatic identification and tracking of visible surface features in real time.

PRINCIPLE OF OPERATION

Two or more cameras which produce digital images are sighted upon the same area. The three-dimensional position of an object within the overlapping field of view of any camera pair is determined by triangulation, if the characteristics of the camera's optical geometry are known. Visible features are located and matched using digital image processing methods.

UNIQUE ABILITIES

Passive monitoring of surface properties, rapid location of any viewable object (x,y,z coordinates).

TYPICAL APPLICATIONS

Precision alignment of large scale structures such as airframes and ship hull segments. Robotics and automation. In a demonstration the system can provide coordinates of recognisable features or target stations on a regular basis.

INTERFACING

Entirely digital, controlled by a microcomputer using digital imaging analysis techniques. Easily interfaced to another computer, data logging or telemetry system.

AVAILABILITY

Specialist technology, commercial products are being developed. Custom applications are feasible with the current technology.

CASE HISTORIES

Has been used for slope monitoring. Commonly used for monitoring industrial and manufacturing processes (machine vision applications).

COMMENTS

Videogrammetry is evolving from the combination of established techniques used in photogrammetry and modern methods from computer vision and image analysis. The technology is beginning to mature and find its way into industrial applications.

ASSESSMENT

Field implementation of a system could be attempted immediately since software for the application exists. The technology is not proven in the field.

This technology offers promise for future use.

REMOTE SENSING

SATELLITE IMAGERY

Earth Observation Satellite Company
Advanced Satellite Productions
Canada Centre for Remote Sensing
Radarsat International

EOSAT Satellite image draped upon digital terrain map of an open pit mine

SPECIFICATIONS

Resolution: to 30 m for Landsat data, to 10 to 20 m for SPOT data.
Data files: 15 km square on 7 x 1.44 Mb floppy disks (Landsat data 512X512 pixels). Proportionally smaller area for SPOT data.
Archive: 1972 - present, depending on satellite. Arrangements can be made to survey particular areas on a pass of the satellite.
Light bands: Visible; red, green, blue
Infrared; thermal, shortwave
Near infrared

MANUFACTURER

Earth Observation Satellite Company
Advanced Satellite Productions
Canada Centre for Remote Sensing
Radarsat International
and others.

COST

Varies with type of service. A typical 512 by 512 pixel image from Landsat (EOSAT) costs $600 (US).

TYPE OF MEASUREMENT

The data available depends on the provider of the service.

EOSC and others provide archived computer images of features upon the earth's surface. Data is available back to 1972. Images can be scheduled in advance for any planned activities.

Various companies and government organizations can provide thematic mapping services.

Advanced Satellite Productions can provide large computer enhanced reproductions for display and other purposes.

PRINCIPLE OF OPERATION

Satellites in orbit above the earth use 7 band imaging equipment to record, and computerised image analysis to map, the earth's surface. The satellites carry a variety of sensors which scan the surface at different scales.

UNIQUE ABILITIES

18 year store of archived images for reference. 30 meter resolution images and maps of geographical change are available from current satellites, and 15 metre resolution is expected in 1994. 10 to 20 m resolution is currently available for some areas from the French SPOT data.

TYPICAL APPLICATIONS
May be useful for preliminary location planning and documenting the history (time of construction) of large dumps for which construction records are poor. This type of imagery has been very useful in the past for public hearings.

Not directly useful for dump monitoring.

INTERFACING
Data is supplied as printed images, on magnetic tape, and on floppy diskette. Software is available to manipulate the images.

Images can be integrated with digital terrain models to created views and maps.

AVAILABILITY
From those listed and others.

COMMENTS
Not directly useful for dump monitoring.

ASSESSMENT
Images are a useful historical reference, resolution is not good enough or expected to become good enough for direct monitoring of dumps.

SPECIFICATIONS
Use of photogrammetric methods for dump monitoring.

MANUFACTURER
Various suppliers in most major cities.

COST
Typically in the order of $1000 per model, varies depending on the number of points picked up.

TYPE OF MEASUREMENT
X,Y,Z Coordinates of identifiable points on the dump.

PRINCIPLE OF OPERATION
Stereoscopic measurement of location of selected points on aerial or oblique photos of the dump.

UNIQUE ABILITIES
Can measure large numbers of points on the surface of the dump. Ortho photos of the dump face or surface can be generated.

TYPICAL APPLICATIONS
Widely used for mapping or measurement applications.

INTERFACING
CADD interpretation and storage of photogrammetry data allows production of maps and other tools. Comparison of digitised images can be used to calculate volumes or rates of movement.

AVAILABILITY
Wide availability.

CASE HISTORIES
Not widely used for dump monitoring but widely used for control of volume in large stock piles.

COMMENTS
Discussion with Kende (1991) indicates that for a large dump, the method would suffer from several disadvantages including:

- Changes in the dump surface and continued filling which would restrict the use to static or abandoned dumps or to permanent stations.

- Requires a new set of photos and a new model for every set of measurements, thus not suited to ongoing measurements.

- Scale problems and problems of placing targets in center of dump restrict the accuracy on a large dump for oblique photos of the front. Accuracies in the order of 0.3 m are attainable for the largest dumps, much better accuracies for smaller dumps.

ASSESSMENT
Not well suited to ongoing measurement of movement. Recommended for volume measurements or for use of the orthophoto technology (either vertical or horizontal).

8.0 DATA SHEETS FOR DATA ACQUISITION, TRANSMISSION AND REDUCTION

8.1 Data Acquisition

Data acquisition is one of the most rapid growth areas within instrumentation in general. Within the last 5 years, the equipment has developed from expensive custom equipment to off-the-shelf "black boxes" that are much easier to install. There continue to be rapid developments in this area.

The equipment shown in the following data sheets concentrates on data acquisition equipment which is capable of real-time transmission of the readings. There is another category of equipment, for which a few examples are shown, which stores readings for later retrieval, often requiring physical access to the equipment. Use of this type of equipment requires that the field unit be interrogated on a frequent basis to prevent critical readings from going unnoticed until it is too late.

Most of the equipment shown was originally developed for one of three different areas of application:

a) Civil engineering applications such as municipal monitoring and control of water systems.

b) Mining applications.

c) Geotechnical applications.

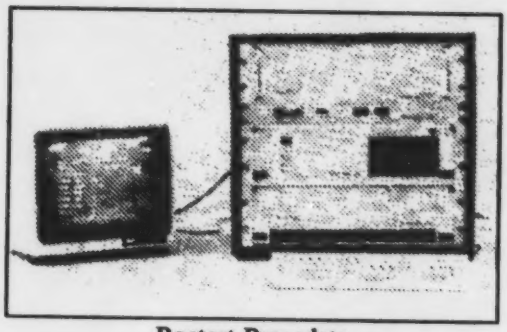
However, due to the versatility of the equipment, much of the experience is transferable across to potential use for dump monitoring. The final choice of data acquisition equipment may depend on what other data acquisition or transmission equipment is already installed in the mine. It should be noted that some of the units may require additional physical protection for installation in a mine.

Data sheets included in this section are as follows:

Data Sheet	Page
Multiple Channel Data Logger	8-3
Portable Computer Data Loggers	8-5
Remote Automated Data Acquisition System	8-7
Remote Terminal Unit (Sierra Misco)	8-9
Field Data Loggers	8-11
Hand held data loggers	8-13

DATA ACQUISITION

MULTIPLE CHANNEL DATA LOGGER



Roctest Procedata

SPECIFICATIONS (Typical)

Power:	120 V with 12 VDC backup
Inputs:	Up to 100 Analog per unit 1000 channels maximum
Display:	40 digit LED or Remote video screen.
Data storage:	Tape, memory, or external disk

MANUFACTURERS

Roctest Limited
Schlumberger Solartron
Logic Beach
Intertechnology
Many others

COST

$10,000 - $50,000

TYPE OF MEASUREMENT

Site data logging and processing. Many loggers can sound alarms if preset limits are exceeded.

PRINCIPLE OF OPERATION

Each system consists of a microprocessor controlled logger which can run a number of boards with logging channels on each. An instrument is connected to each channel. The logger measures the characteristics of the electrical signal produced by the instrument response, and stores the information in digital form. Information can often be displayed upon a video screen in engineering units in real time, and external devices can often be controlled based upon numerical and logical comparisons performed in the microprocessor.

UNIQUE ABILITIES

Runs unattended, can store large volumes of data.

TYPICAL APPLICATIONS

Data collection in dams, tunnels, buildings, soils, rock slopes, and foundations.

INTERFACING

Can export data to portable computers.

AVAILABILITY

Off the shelf

CASE HISTORIES

Many installations in sites where a source of power is available.

COMMENTS

Basic data loggers have been produced by a variety of firms for general applications for nearly 15 years. In addition, some firms making specialist instruments produce propri-

proprietary logging systems allowing automated instrument reading.

The capabilities of the equipment and suitability for use in a mining environment vary greatly.

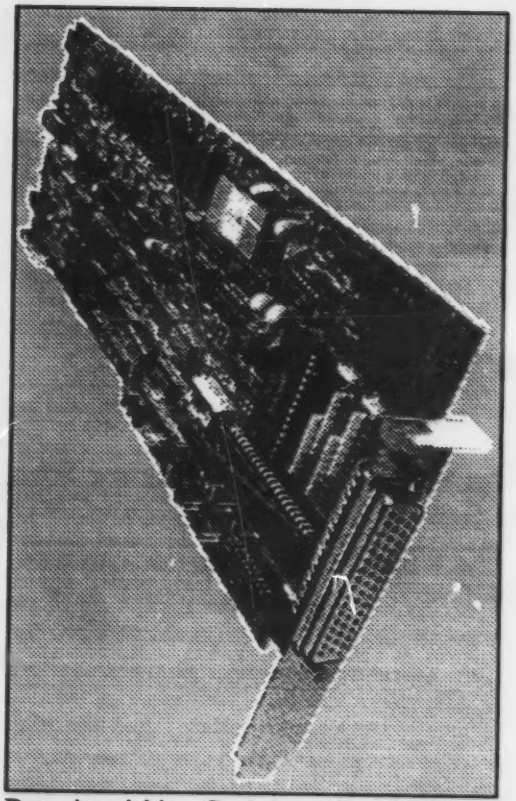
ASSESSMENT

The final selection of this equipment depends upon individual features and would require further investigation by instrument installers. Basic loggers are usually limited in their ability to offer "intelligent" response to alarm conditions. PC based logging systems are usually cheaper per channel, and more versatile than non-specialist loggers but may be less robust.

Use of equipment which requires polling to download stored readings is only recommended if specific procedures are put in place to ensure that readings are interpreted and used on a timely basis.

DATA ACQUISITION

PORTABLE COMPUTER BASED LOGGERS



Data Acquisition Card for a Portable Computer

SPECIFICATIONS

Expansion cards and software to enable logging from a portable computer.

Power:	120 V
Inputs:	8 or 16 channels per card Up to 6 cards per computer
Display:	Video screen, graphics
Data storage:	Memory, hard or floppy disk(80 Mb)
Mass storage:	optical disk, tape(2000 Mb)

MANUFACTURER

Strawberry Tree Incorporated
United Electronic Industries
Laboratory technologies Limited
Capital Equipment Corporation
Quadtech
Advantech Corporation
Many others

COST

Approx. $1,000 per card
Approx. $3,500 per portable computer (must be capable of accepting add-in cards).
Approx. $1,500 for software per computer

TYPE OF MEASUREMENT

Site data logging and processing. The computer is capable of displaying very high quality graphics, and controlling systems and alarms. Portable computers are often used to communicate with field loggers via appropriate interfaces.

PRINCIPLE OF OPERATION

The main processor in the computer is used to read analog and digital data via external card interfaces. The computer can use all its facilities to process, interpret, and store data.

UNIQUE ABILITIES

Very powerful, quick, versatile, and ever cheaper processing power.

TYPICAL APPLICATIONS

Data logging where a source of power is available.

INTERFACING

Can communicate with any device through easily available hardware interfaces. Used to control many networks.

AVAILABILITY
Off the shelf. Mail-order

COMMENTS
The diversity of available hardware and software can lead to compatibility problems. Quality of components is variable. For continued unattended use in the field, additional protection (eg., an instrumentation house) would be required since most computers are not environmentally protected.

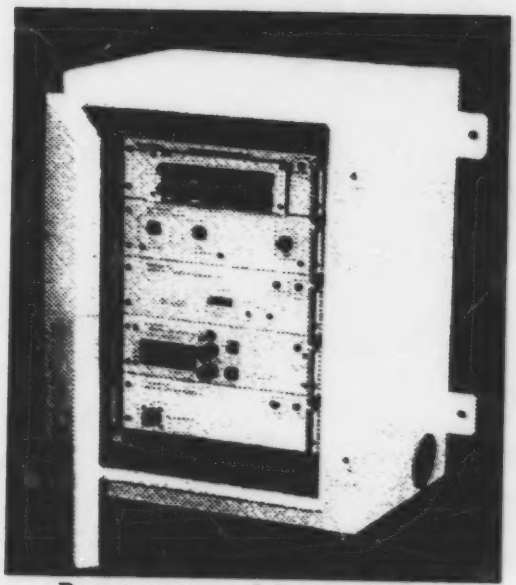
Very versatile equipment.

ASSESSMENT
Not particularly well suited to field logging except where all signals can be diverted to a central building or station which houses the computer. Cheapest of all data logging options where post-processing and display are required.

DATA ACQUISITION

REMOTE AUTOMATED DATA ACQUISITION SYSTEM

Synergetics International - Series 3400



Remote automated data acquisition
remote terminal unit

SPECIFICATIONS

Series of modular control, data acquisition and communication modules which can be configured to meet specific site needs. A field unit consists of:

- Master control module - 3401B
- Data acquisition modules - 3452,3453,3455
- Memory module - 3461
- Communication modules

Power:	10.5→15 VDC, 4→300 mA
Inputs:	analog, serial I/O
A/D resolution:	13 bits

Communication:

- satellite: GOES, ARGOS, Meteosat, and GMS
- Radio: VHF, UHF, Microwave
- Telephone: Cable, leased, cellular

MANUFACTURER

Synergetics International, Incorporated

COST

Project specific, depends upon modules required and number of channels to be logged. $5,000 to $25,000

TYPE OF MEASUREMENT

Remote automated data acquisition system for collection and transmission of field data. Interpretation of the data can be made in the field, and "intelligent" decisions made on site. The field processor can control devices in the field to take samples and operate machinery, and control a local net of remote data acquisition terminals.

PRINCIPLE OF OPERATION

A central computer (RTU) controls field units which have a time based sleep function so that they draw minimal power while not sampling data. The field units awake to read, process and transmit data via one or several chosen media. The field unit can be interrogated and programmed from the RTU which in turn is in communication with a computer in the office.

UNIQUE ABILITIES

Ability to transmit over several media, simultaneously if required. Ability to control local devices (pump, winch, etc). Abili[illegible] f remote units to control a local communications net.

TYPICAL APPLICATIONS

Field acquisition of meteorological and environmental data.

INTERFACING

Satellite, radio, and telephone modules.
RS-232 port.

Local radio and telephone nets.
36 sensor inputs, 8 digital outputs

AVAILABILITY
Off the shelf

CASE HISTORIES
Meteorological and dam monitoring: US Corps of Army Engineers, US Bureau of Reclamation, US National Weather Service

COMMENTS
Highly sophisticated equipment for remote data acquisition and transmittal via almost any means.

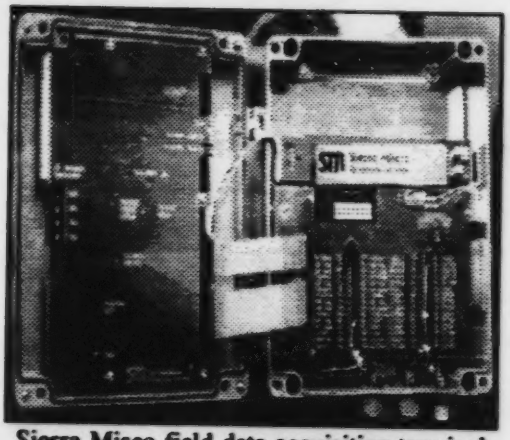
This type of equipment is an example of the most sophisticated level of data acquisition and processing. The company provides a complete package which is capable of providing all data acquisition services including the field collection of data, automatic transmission of the data to the office, processing of the data, alarms if trends are exceeded, and plotting of the data. The data can also be provided in a format suitable for use in other programs.

ASSESSMENT
Recommended for use in a limited number of situations particularly on remote mine sites where the communication facilities of the equipment are an asset. For many mining situations a simpler and less costly system would be adequate.

DATA LOGGING

REMOTE TERMINAL UNIT

Sierra Misco - RTU 0850N



Sierra Misco field data acquisition terminal

SPECIFICATIONS

Power: 10 → 16 VDC, 60 mA → 1 A
Temperature range: -40 → 60°C
A/D conversion: 10 bit
I/O: 7 → 14 analog inputs
1,2 Digital counters
8 Digital status inputs
1,2,10, Digital status outputs
20 pin parallel port
Telemetry: radio, telephone communication modules

MANUFACTURER

Sierra Misco

COST

$6,000 or more depending upon required degree of customizing. Could be less if minimal software is purchased.

TYPE OF MEASUREMENT

Automatically collects and transmits data from a remote location to a central station. The central station is PC based and can have customised software to display graphics and perform control functions.

PRINCIPLE OF OPERATION

The system features integrated data acquisition and telemetry capabilities. It is assembled as a modular system based on a controller and a number of optional modules, and uses advanced packet switching and error detection to ensure reliable transfer of data. The system is capable of controlling two devices at the site.

Each field unit also serves as a relay station which enables a transmission network to be established in a geographic region. Redundant paths can be established to ensure reliable transmission of data from one end of the net to the other.

UNIQUE ABILITIES

Data transmission error detection, prioritising of alarm data, remote programming. Good local area networks for ensuring reliable data transmission.

TYPICAL APPLICATIONS

Remote data collection where prompt and reliable transmission of data is required.

INTERFACING

Portable or base station computers
Display
Telephone system
VHF/UHF transmitters

AVAILABILITY

Off the shelf

CASE HISTORIES
Widely used around the world. Has been installed in a few mines in Canada.

COMMENTS
Highly sophisticated system with many important telemetry features. Field system designed for use in the field. The system would be adapted to the particular requirements at a mine. One disadvantage is that special setup of the input channels is required to read millivolt inputs.

ASSESSMENT
useful, recommended for consideration.

DATA ACQUISITION

FIELD DATA LOGGERS

RST Instruments - Borehole loggers, Data Trapper
ACR systems Inc. - Micro loggers, stick-on loggers

RS Technical Instruments
NEMO4 and borehole loggers

SPECIFICATIONS (Typical)

Power:	0.1 mA sleep 6 mA.s wake 6 mA.s transmit
Operating temperature:	-40 → 75°C
A/D:	12 bit (accuracy 0.25%)
I/O:	8, 16 channel, 1 counter, 7 digital inputs, 1 strobe
Memory:	32,000 samples, non volatile
Weight:	.65 kg
Size:	240 x 120 x 100 mm

MANUFACTURER
R. S. Technical Instruments Limited
ACR Systems Incorporated
Others

COST

RS Technical	$2,000 to $5,000
depends largely upon ruggedness of case.	
ACR Systems	$500 to $900

TYPE OF MEASUREMENT
Multi-channel, low cost, battery powered data logger designed for reliable unattended operation for geotechnical work.

PRINCIPLE OF OPERATION
The data logger is housed in a rugged sealed case to protect it in rough working conditions. The RST downhole version is cased in a 115 mm diameter cylinder. It has software controlled data logging functions which read resistances and voltages, and has a 4800 baud direct data dump function. Will operate via a modem at 1200/2400 baud.

The ACR loggers are single or double channel loggers for above ground use. Batteries will last up to 10 years. Unit weight is only several hundred grams.

UNIQUE ABILITIES
Relatively inexpensive field data loggers capable of being polled from an office computer. Rugged casings intended for geotechnical use. Very long battery life.

TYPICAL APPLICATIONS
Field monitoring of geotechnical data, and down-hole logging.

INTERFACING
Modem via RS-232 port
Micro computer with dedicated software

AVAILABILITY
Off the shelf

CASE HISTORIES

Quite new products finding increasing numbers of applications because of their size and cost.

COMMENTS

Suitable for a wide variety of data logging tasks. This type of equipment must be interrogated regularly so that key data is interpreted in a timely manner. The RST loggers are manufactured by a geotechnical instrumentation firm.

This type of equipment is most appropriate for dump monitoring where telephone or other routine connections to the data logger are feasible.

The micro-electronics which form the processing heart of this type of logger are becoming very inexpensive and equipment of this general type is becoming widely available.

ASSESSMENT

Recommended for consideration where data can be downloaded on a frequent basis for timely interpretation or for situations where historical data is required which only needs to be downloaded every few weeks.

DATA ACQUISITION
HANDHELD LOGGERS
Omnidata
Campbell Scientific

Nikon handheld logger

SPECIFICATIONS
Hand held data loggers often supplied as part of an equipment package.

MANUFACTURER
Omnidata
Campbell Scientific
Others including surveying companies

COST
Approximately $5,000

TYPE OF MEASUREMENT
Digital data storage

PRINCIPLE OF OPERATION
The logger is temporarily connected to the instrument which is producing data. The data is stored and later dumped to a processing computer.

UNIQUE ABILITIES
Small, portable loggers for a variety of tasks. Saves transcription of field data.

TYPICAL APPLICATIONS
Surveying and experimental data packs. Most commonly used with devices that have IEEE or RS-232 interfaces to record data.

INTERFACING
IEEE and RS-232 ports
Portable computers

AVAILABILITY
Off the shelf

CASE HISTORIES
This type of equipment has been widely supplied as part of original equipment packages and has also been adapted to log readings from manually read equipment such as Slope Indicators.

COMMENTS
Can be left to run unattended.

ASSESSMENT

Small loggers, not very robust, other loggers of the same price are better suited for unattended mine use. Use of these devices is usually restricted to logging data from equipment in the field on a short term basis and the logger is then taken to the office to dump the data into a larger computer. Good for field trip experimental data, survey data collection and storage, and for use with global positioning system devices.

8.2 Data Transmission

Much of the equipment shown in this section was originally developed in concert with the data acquisition equipment discussed in the preceding section. As a result, at least some of the equipment and software is designed to work with the associated data acquisition equipment and data reduction and control software. Equipment dependencies should be explored before finalizing the specification.

There are a wide variety of transmission methods available including:

a) Radio using a variety coding schemes and transmission methods. The equipment varies from short range FM transmitters designed for local work (40 km) to long range, but low power, meteor burst transmitters (2000+ km).

b) Satellite transmission. Note that both the U.S. and Canada make satellite transmission channels available. In some cases where the channel is transmitting information of national interest, such as rainfall data, it may be possible to use a satellite channel at reduced charges.

c) Telephone line transmission.

d) Computer transmission nets such as DataPac.

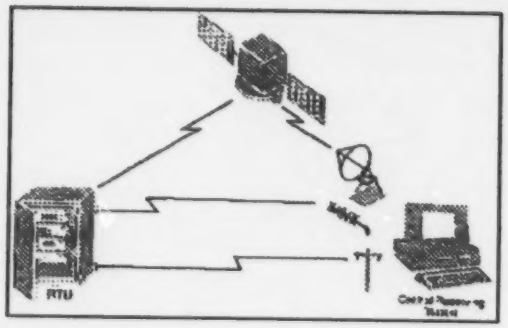
Data sheets include the following:

Data Sheet	Page
Direct connect modem	8-17
Satellite transmitter	8-19
Radio module	8-21
Meteor burst communication network (master station)	8-23
Meteor burst communication network (remote station)	8-25
Autosequencer	8-27
Infrared receiver	8-29
Global Positioning System Interface	8-31

COMMUNICATIONS

DIRECT CONNECT MODEM

Synergetics International - 3422A



SPECIFICATIONS

Power: 10.5 → 15 VDC, 1.1 → 47 mA
Baud rates: 300 baud, full duplex
Operating temperature: -40 → 55°C
Size: 2.6 x 10 x 10 inches
Weight: 3.2 pounds

MANUFACTURER

Synergetics International, Inc.
Many others

COST

$2,000

TYPE OF MEASUREMENT

The modem transfers information asynchronously over domestic and international switched telephone networks.

PRINCIPLE OF OPERATION

The modem is controlled via a slave port at the remote terminal unit. It sends and receives information at 300 baud rate over FCC registered voice grade switched telephone networks. The modem has auto-dial, and auto answer facilities.

TYPICAL APPLICATIONS

Would be installed as part of a remote data acquisition system where telephone lines or cellular telephone service is available.

INTERFACING

Interfaces to Synergetics series 3400 remote data acquisition system via the master control unit (3401).

AVAILABILITY

Off the shelf.

CASE HISTORIES

Has been used to monitor B. C. Hydro dams.

COMMENTS

Slow transmittal rates compared to other PC type modems.

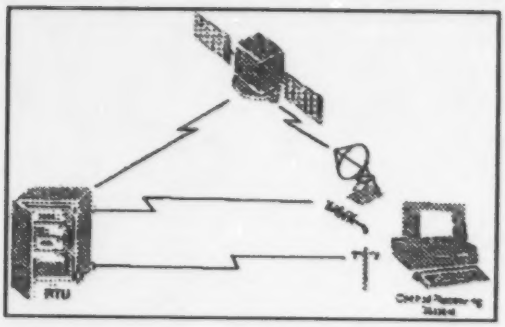
ASSESSMENT

Suitable for use with the vendors equipment. Higher speeds would be desirable.

COMMUNICATIONS

SATELLITE TRANSMITTER

Synergetics International - 3421A, 3421B, 3421C



SPECIFICATIONS

Power: 10.5 → 15 VDC
5.3 mA (quiescent) → 3.1 A (transmit)
Operating temperature: -40 → 55°C
Size: 2.6 x 10 x 10 inches
Weight: 5.4 pounds
Power output: 2 → 13 Watts
Channels and frequencies:
- 401.7010 → 402.0985 MHz
- GOES channels: 1-199
- International GOES channels: 202-266

MANUFACTURER

Synergetics International, Inc.
Others

COST

Site specific depending upon required transmission distance and atmospheric conditions.
$2,000 to $3,000

TYPE OF MEASUREMENT

The satellite transmitters are frequency agile UHF transmitters which relay digitally encoded information via satellite to master stations. The data is downloaded from the master stations via landlines.

PRINCIPLE OF OPERATION

The transmitters operate by relaying signal transmission through satellites in geosynchronous orbit. They support every internationally available satellite operation mode and channel.

UNIQUE ABILITIES

The transmitters have built-in monitoring systems that provide status and performance information such as; transmission power, channel selection, and condition and error flags.

TYPICAL APPLICATIONS

Transmission of data from remote automated collection sites.

INTERFACING

All Synergetics series 3400 modules, and other manufacturers systems (check with manufacturer).

AVAILABILITY

Off the shelf.

CASE HISTORIES

Used for relaying meteorological, hydrological and logged instrumentation data.

COMMENTS

Satellite transmission may only be justified from a remote site without telephone service where data is required in the office. Normally satellite communication would only be considered for monitoring abandoned remote dumps where no infrastructure exists. Ideally suited for office monitoring of a site where there are no personnel resident.

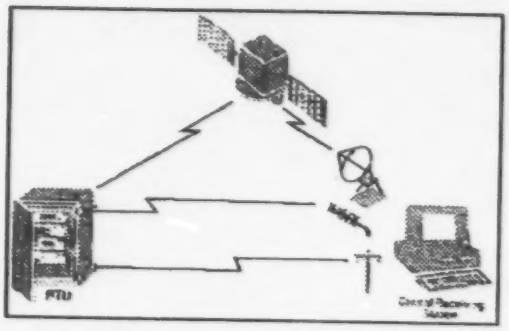
ASSESSMENT

Recommended for use only where other means of transmission are not feasible. See in particular the data sheet on meteor burst communication for other alternatives.

COMMUNICATIONS

RADIO MODULE

Synergetics International - Series 3431-A, 3423-C



SPECIFICATIONS

Power:	10.5→15 VDC
Operating temperature:	-40 → 55°C
Altitude:	0 → 20,000 feet
Size:	3400 module

MANUFACTURER

Synergetics International, Inc.

This type of equipment is also available from other manufacturers, for example, Sierra Misco.

COST

Approx. $1,000

TYPE OF MEASUREMENT

The 3431A provides a radio communication link for data collection.

PRINCIPLE OF OPERATION

The module is designed for use with Motorola and E.F. Johnson radios which are supplied with the module. The choice of frequencies depends upon the application. The module interfaces with the field data acquisition unit and transmits data to a master receiving station.

TYPICAL APPLICATIONS

Remote field data collection.

INTERFACING

With all Synergetics series 3400 modules, and other data acquisition systems (check with Synergetics or other manufacturers).

AVAILABILITY

Off the shelf.

CASE HISTORIES

The cheapest form of telemetry, and often most popular for short range (up to 40 km) communication.

COMMENTS

Short range radio communication provides an effective way to take data from a waste dump to a local mine office. Note that it may also be possible to "piggy back" data on an existing communications network in the mine.

Some form of error detection is required to determine if data is received verbatim at the intended source. Sierra Misco make effective use of error detection in radio relay systems.

ASSESSMENT
Recommended for use where required.

COMMUNICATION

METEOR BURST COMMUNICATION NETWORK

Meteor Communications Corporation - 6560 and 6530 master stations

SPECIFICATIONS

Master station

Message Length:	1 → 8000 Characters
Destinations:	1 → 99
I/O interfaces:	4 RS-232, 300 → 9600 baud
Transmission Power:	500 W

Portable Master Station

Power:	110/220 VAC, 20/10 A
Operating temperature:	0 → 50 °C
Size:	14 x 11 x 18 inches
Weight:	100 pounds
I/O:	1 RS-232, 300 → 9600 baud
Transmission Power:	500 W
Range:	1600 km

MANUFACTURER

Meteor Communications Corporation

COST

Approx. $35,000 for a master station, antennae and power source extra.

TYPE OF MEASUREMENT

Data transmission to and from other master stations and remote stations in the network.

PRINCIPLE OF OPERATION

The master stations reflect 37 - 60 Mhz radio signals off ionised trails left by meteors as they enter and disintegrate in the earth's upper atmosphere. When a second station receives the signal, a short communication window is established in which the stations can communicate. The window remains open only until the reflecting path is dispersed. Wait times between communication windows can range from a few seconds to several minutes.

UNIQUE ABILITIES

Transmission of data and communications over very long distances from remote areas without resorting to satellite transmission..

TYPICAL APPLICATIONS

Communications in far northern regions, and data collection from remote acquisition stations.

INTERFACING

With other MCC stations

AVAILABILITY

From MCC

CASE HISTORIES

Many in military, scientific and communication applications. MCC operate a commercial base station in Victoria (on Saturna Island)

COMMENTS

Some networks are being run as commercial ventures. Transmission of data does not necessarily require purchase of a master station if an existing network is being run which can reach the intended dump site. Victoria can communicate with most of south and central B.C and some parts of northern B.C. There are many base stations in operation in Alaska.

ASSESSMENT

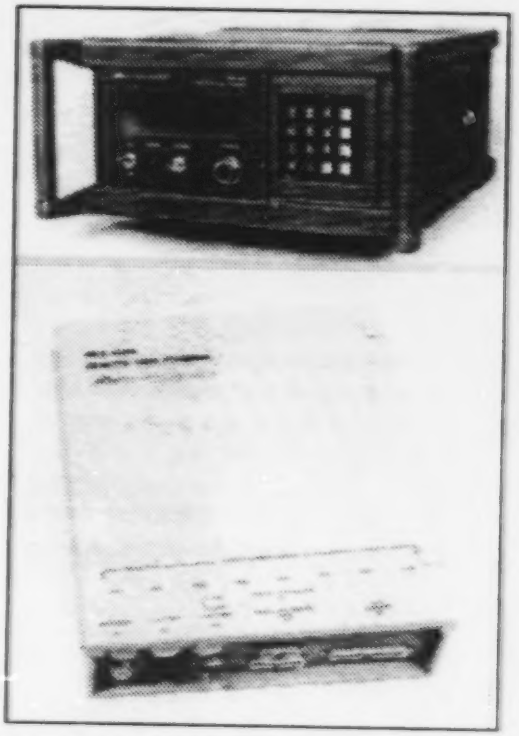
Mainly provides an alternative to satellite communication which is under local control and which may be less expensive. Suitable for data transmission within a very widespread mine, or from a remote location to the office. Would not normally be required if land lines or ordinary radio communication are available.

COMMUNICATION

METEOR BURST COMMUNICATION NETWORK

Remote Station and Data Logger

Meteor Burst Communication - Remote Stations 540B, 540C, 550B



SPECIFICATIONS

Power:	12, 24 VDC, 32 mA (standby) → 20 A (transmit)
Operating temperature:	-30 → 50°C
Data rate:	2 → 8 kb/s
Range:	1600 km
Transmission power:	200 W
I/O:	RS-232

550B terminal

I/O:	16 analog sensors, 3 counters, serial and parallel ports
Accuracy:	12 bit resolution

MANUFACTURER

Meteor Communications Corporation

COST

Typical field unit $5,000

TYPE OF MEASUREMENT

Data transmission to and from master stations in the network. The 550B incorporates a data logger and acts as a self sufficient data logging and communications terminals.

PRINCIPLE OF OPERATION

Master stations reflect 37 - 60 Mhz radio signals off ionised trails left by meteors as they enter and disintegrate in the earth's upper atmosphere. When a remote station receives the signal a short communication window is established in which the stations can communicate. The window remains open only until the reflecting path is dispersed. Wait times between communication windows can range from a few seconds to several minutes.

UNIQUE ABILITIES

Transmission of data and communications over very long distances. The 550B can log measurements on site, control devices on site and prioritise alarm transmissions.

TYPICAL APPLICATIONS

Communications in far northern regions, and data collection from remote acquisition stations.

INTERFACING

With data logging apparatus, and portable computers.

AVAILABILITY

From MCC

CASE HISTORIES

Many in military, scientific and communication applications.

COMMENTS

Some networks are being run as commercial ventures. Transmission of data does not necessarily require purchase of a master station if a network is being run which can reach the intended dump site.

Sierra Misco have data acquisition systems which interface directly with meteor burst communication remote stations.

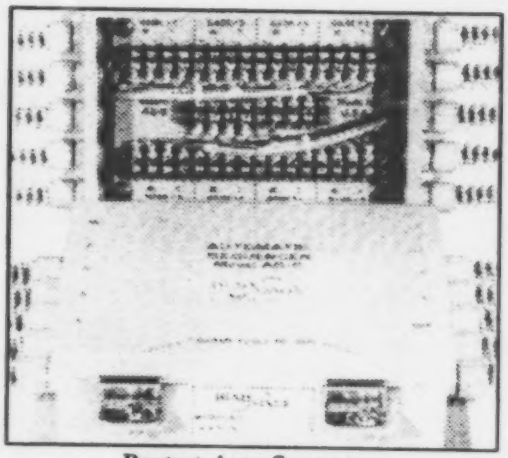
ASSESSMENT

Recommended for use in remote areas where there is a lack of land lines and where transmission from the remote site is required. This type of technology could be considered over a widespread mine site, or over distances up to 1600 km to provide data transfer. Would not be required at many mines where on-site infrastructure and telephone lines are available.

COMMUNICATION

AUTO SEQUENCER

Irad-Gage - Model AS8



Roctest Auto Sequencer

SPECIFICATIONS

Power:	though power supply from logger
I/O:	8 channels
Control:	From data logger
Switching:	2 relays per channel
Weight:	2.5 kg
Size:	150 x 150 x 100 mm

MANUFACTURER

Irad-Gage

SUPPLIER

Roctest Ltee

COST

Contact Supplier

TYPE OF MEASUREMENT

The unit allows sequential reading of eight remote vibrating wire gauges or 2 and 4 wire transducers.

PRINCIPLE OF OPERATION

The unit incorporates 16 relays which are controlled by the data logger to switch the sensors sequentially onto the communications line.

UNIQUE ABILITIES

Reduces the number of long cable runs.

INTERFACING

The auto-sequencer is controlled by Irad-Gage's data loggers.

AVAILABILITY

Off the shelf

CASE HISTORIES

Used in field installations for data logging

COMMENTS

Manufactured by the leading supplier of vibrating wire gauges and is compatible with this type of instrumentation.

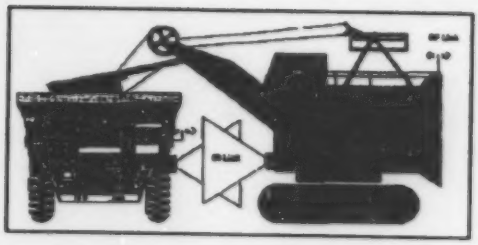
ASSESSMENT

Recommended for use where required.

DATA TRANSMISSION

INFRARED TRANSCEIVER

Modular Mining Systems - Infrared transceiver



Infrared transceiver

SPECIFICATIONS

Power:	13.8 VDC, less than 1 A
Operating Temp:	-20 → 70 °C
Range:	→ 20 m
Data rate:	9,600 bps via IR
	19.2 Kbps via SDLC loop

MANUFACTURER
Modular Mining Systems

COST
$900 per unit, two units required per installation

TYPE OF MEASUREMENT
Short range data transmission by infrared light.

PRINCIPLE OF OPERATION
Transmitting and receiving units placed within line of sight shorter than 20 m transmit encoded information.

UNIQUE ABILITIES
Transmission of information using light transmitted through space.

TYPICAL APPLICATIONS
Communication between mining haulage truck load cell and loading shovel operator. Transmit coded information to road side receivers.

INTERFACING
Connects to truck mounted load cell.

AVAILABILITY
From Modular Mining Systems

CASE HISTORIES
Similar equipment is used at several Canadian mines.

COMMENTS
Can probably be connected to most digital equipment and would be capable of providing short range signal transmission across the dump.

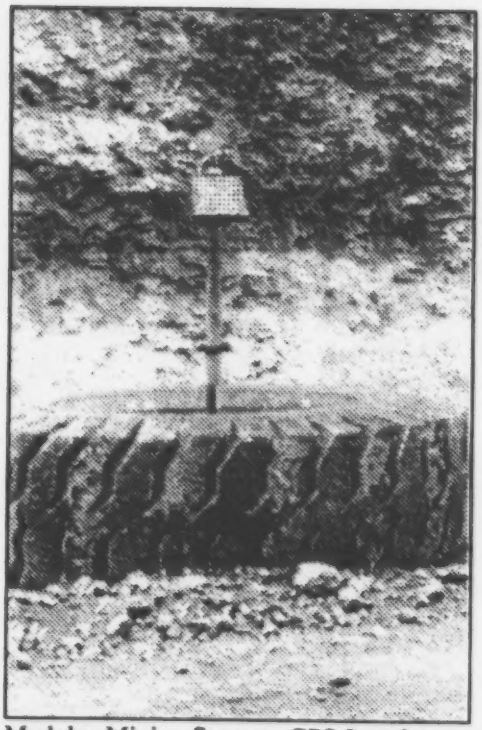
ASSESSMENT
In its present configuration, this equipment is not capable of providing a sufficiently long transmission path to be capable of providing routine coupling of instrumentation across the dump. However, developments of this or similar technology would be useful in provid-

ing short range linking of instruments on the dump.

POSITION FIXING

GLOBAL POSITIONING SYSTEM INTERFACE

Modular Mining Systems - GPS Interface



Modular Mining Systems GPS Interface

SPECIFICATIONS

For use with MMSI DISPATCH system.

Power:	13.8 VDC, less than 5A
Operating Temp:	-20 → 70 °C
Altitude:	-30 → 3700 m
Display:	Onboard 32 char LED, audible alarm.
Transmitter:	Integral 1200 baud radio modem.

MANUFACTURER

Modular Mining Systems

COST

Contact manufacturer

TYPE OF MEASUREMENT

Easting, northing and elevation of the GPS receiver station are derived from satellite signals. The information is sent automatically to a mine management computer.

PRINCIPLE OF OPERATION

The device receives digital information from the GPS receiver and transmits it by FM radio net to a central computer where logging and calculations of differential position of the receiver can be made.

UNIQUE ABILITIES

Automated remote collection and transmission of GPS data.

TYPICAL APPLICATIONS

At present time, location record of mine machinery. See further comments below.

INTERFACING

Designed for use with MMSI DISPATCH system.

AVAILABILITY

From MMSI after June, 1991.

CASE HISTORIES

GPS is being used to monitor dam movement by the U.S. Corps of Army Engineers and by B.C. Hydro. The accuracy quoted by the Corps is in the order of ± 5 mm over distances of 5 km.

COMMENTS

Off the shelf product for automated GPS measurement. This equipment is specifically design for use with trucks to provide location

data. However, it provides some insight to the possibilities of using GPS and existing hardware/software in a mine to provide monitoring and data reduction possibilities for monitoring of waste dumps.

ASSESSMENT

GPS technology is well developed and is starting to be deployed as a movement monitoring system. First order surveying accuracy can be achieved using GPS. GPS or similar future systems will likely be used for routine monitoring in the future, although at present the cost may be prohibitive.

See further comments in the report and on the applicable data sheets.

8.3 Data Reduction

Of all of the various categories of instrumentation and associated software, data reduction and alarm software is the least developed. Many of the systems are custom programmed, or at least proprietary to a particular acquisition/transmission system. There may be a window of opportunity for writing software to interface with the measuring system to be sold at a reasonable cost.

Much of the software available was originally developed for both a control and monitoring function for use in fields such as municipal engineering. For the purposes of mine monitoring, the control functions are not normally required, and results in increased cost and complexity.

There are several software items which are presently under development or which were not available in time for inclusion in this report. These include:

a) Software under development for the U.S. Army Corps of Engineers by Woodward Clyde Consultants.

b) Other software apparently developed by Woodward Clyde. There appears to be some difficulty with shipping this material to Canada and at the time of preparation of this report, HBT had not yet received a copy.

c) Software under development by the Norwegian Geotechnical Institute (NGI).

In the absence of software specifically developed for geotechnical monitoring, there are several other possibilities:

a) Use of off-the-shelf software such as communications programs and Lotus 123, both of which offer macro or script capabilities. With an overall master or batch program, these systems would be capable of calling a remote modem equipped station, downloading the data and processing it. However, the package would be cumbersome and could be difficult to debug.

b) Most vendors of data acquisition units provide some level of software support which should be carefully evaluated at the time of purchase. In fact, one of the greatest differences between many of the units may be in the software which is available. A lot of the proprietary software which is available is relatively

expensive with prices up to or more than $6000 for some of the more sophisticated programs.

Because of the wide range of proprietary software which is available and which is usually part of a data acquisition equipment package, this section of the report provides only a brief sample of some of the unusual programs which are available.

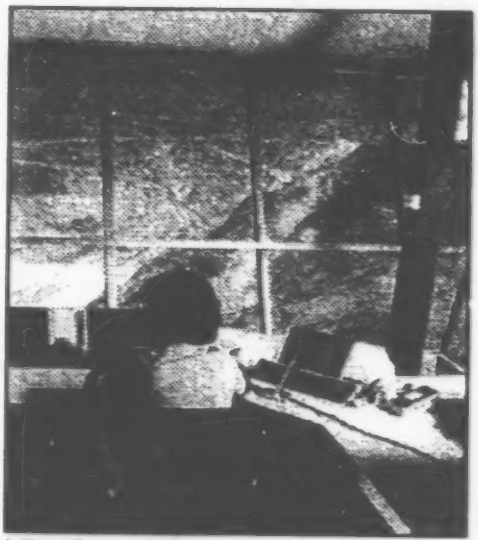
Data sheets in this section include the following:

Data Sheet	Page
Mine Operations Monitoring and Control	8-35
Slope Monitoring System	8-37
Terrain Modelling Software	8-39

SOFTWARE

MINE OPERATIONS MONITORING AND CONTROL

Modular Mining Systems - DISPATCH



Mine Control Centre

SPECIFICATIONS

Software for mine truck control and dispatch to aid efficiency and safety. This company's modified tripod monitor may be interfaced with this software. Software is for use on workstations or mini-computer.

MANUFACTURER

Modular Mining Systems

COST

Available as part of customised installations.
Typical costs are:

For each truck and shovel	$15,000
Software and location beacons	$200,000

TYPE OF SYSTEM

A central computer receives information from FM transmitters located upon trucks, roads, equipment, and instruments via a local FM network. With help from the computer a human controller processes information, and transmits instructions to machinery operators on site.

Other instrumentation may be interfaced with the system.

PRINCIPLE OF OPERATION

Local FM radio net (line of sight communications) feeds information to and from a central computer with mine management software. Automatic comparison of new information with preset parameters allows immediate integration of instrument data into the decision process.

UNIQUE ABILITIES

Data from field instruments (for instance GPS via an interface) is analysed automatically, and alarms given over dispatch system to all operators on site. Allows control of rate of dumping to reduce risks and complete shutdown of dump site at short notice.

TYPICAL APPLICATIONS

Monitoring and control of large open pit mines.

INTERFACING

FM transmitters interface with engine computers, and will receive analogue and digital inputs and outputs from field instruments and loggers.

AVAILABILITY

From Modular Mining Systems

CASE HISTORIES

26 installations in Canada, the USA, and the world. The Canadian installations are at:
Highland Valley Copper,
Iron Ore Company of Canada Ltd.,
Quintette Coal,
Westar Mining Company.

COMMENTS

Modular mining Systems are developing a wire extensometer slope monitor for use specifically with their network software. Other monitoring instruments will interface easily with the FM transmission hardware. The warning functions for the slope data are built into the program, other data may require alterations to the program to integrate the alarm and post function.

ASSESSMENT

Useful, available system to integrate monitoring into daily operations in the mine. Typically used in large mines where costs can expected to be recovered due to increased utilisation and efficiency.

SOFTWARE

SLOPE MONITORING SYSTEM

Geodimeter - SMS

Sierra Misco

SPECIFICATIONS
Software to control Geodimeter 140 robot theodolite and calculate slope stability

MANUFACTURER
Geodimeter in association with Quebec Cartier Mines and Queen's University, Kingston, Ontario.

COST
Includes control software for theodolite

TYPE OF MEASUREMENT
Calculates movement of targets measured by the total station. Controls theodolite reading rate and data reduction.

PRINCIPLE OF OPERATION
Connected to the theodolite the software controls its actions and reduces the data. The frequency of readings can be altered when predetermined movement limits are exceeded.

UNIQUE ABILITIES
Automated calculations for EDM.

TYPICAL APPLICATIONS
Monitoring of open pit mine slope stability.

INTERFACING
To Geodimeter 140 theodolite.

AVAILABILITY
Specialist software

CASE HISTORIES
Quebec Cartier has a version of this equipment installed for open pit monitoring.

Noranda considered the system and did not install it due to equipment availability problems.

COMMENTS
Queen's University have written additional software for the theodolite installation at Quebec Cartier mines.

ASSESSMENT
This type of equipment and software will allow the automation of EDM and theodolite readings, and will reduce the costs that are associated with large intensive total station monitoring programs.

SOFTWARE

TERRAIN MODELLING SOFTWARE

Gemcom - Geo-Model and Mine-Survey

Gemcom Geo-model

SPECIFICATIONS
Micro-computer software for mapping and terrain modelling.

MANUFACTURER
Gemcom

COST
Contact supplier

TYPE OF MEASUREMENT
Interpretation of survey data.

PRINCIPLE OF OPERATION
Data reduction and analysis for mining applications. Creates graphical models of survey data for easier interpretation.

UNIQUE ABILITIES

TYPICAL APPLICATIONS
Mine management. Could be used for iterative analysis of slope movement data.

INTERFACING
Surveying data loggers.

AVAILABILITY
Off the shelf.

CASE HISTORIES
Iron Ore Company of Canada
Luscar Ltd.
Manalta Coal Limited
Princeton Mining Corporation
and others

COMMENTS
Could be integrated with data acquisition hardware to form automatic slope analysis software.

ASSESSMENT
Not available as an automated slope monitoring software package.

9.0 LIST OF REFERENCES AND LIST OF SUPPLIERS

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Wittke W., Personal Communication with Prof. Dr. Ing. W. Wittke (1991) (Aachen, F. R. Germany).

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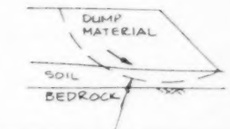
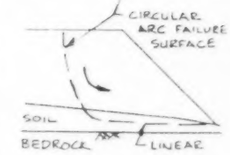
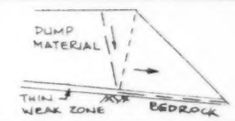
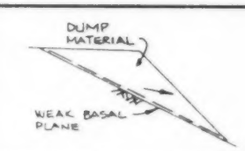
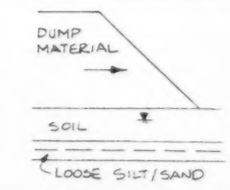
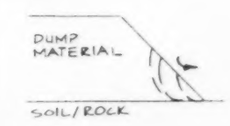
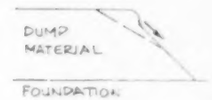
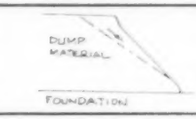
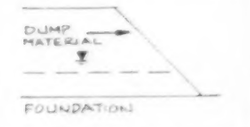
Table 3-1 Summary of Deformation Modes of Typical High Waste Dumps

Mode	Type of Failure	Description	Characteristics of Movement	Comments	Potential for Detection using Monitoring	Types of Monitoring (Typical)	Unusual or Special Types of Monitoring	Sketch
Base and Foundation Failures	Rotation failure	Mass failure along a circular or curved surface which may extend into the foundation soils.	Perpendicular to movement vectors locates center of rotation. Movement vectors are oriented along circular arc and have different orientations on different parts of the failure.	Not a typical failure mode. Weak foundation soils can contribute to this mode.	Good. Movements may be large before ultimate failure.	Wireline extensometer. Buried extensometer. Surface tiltmeter. Surface Settlement. EDM or other survey methods. Piezometer.	Borehole inclinometer. Acoustic emission. GPS.	
	Non-circular failure.	Part of failure surface follows a weak zone.	May be a combination of rotational movement (curved part of surface) and translational movement along more linear part of surface. Movement vectors linear along non-curved part and varied along curved part.	A typical mode of failure of dumps. Note that monitoring may not be able to distinguish between this case and the case above, depending on locations where movement vectors are measured.	Good. Movements may be large before ultimate failure.	Wireline extensometer Buried extensometer Surface tiltmeter Surface Settlement EDM or other survey methods. Piezometer	Borehole inclinometer Acoustic emission GPS	
	Wedge Failure.	Part of failure zone follows weak zone. A graben may be present in upper part of failure.	Translational movement of two or more wedges with inter-wedge shearing. Two or more vector directions.	Frequent failure mode of weak dump material over foundation containing low strength zone. Less frequent in high dumps.	Good. Movements may be large before failure	Wireline extensometer Surface settlement EDM or other survey methods. Piezometer	Borehole inclinometer Acoustic emission GPS	
	Base translation	Sliding of bulk of dump along weak basal plane.	At start of failure, there may be little shearing within the dump unless the weak zone is non-planar. Movement vectors similar across slide area.	Typical failure mode of dumps built almost entirely on weak foundation materials. Dump may break up during movement. This type of failure has occurred on moderately high dumps in B.C. in the past.	Difficult to detect with tripod monitors. Easily detected with systems that reference movement to non-moving reference.	Borehole inclinometer EDM or other survey methods. Piezometer	Acoustic emission GPS	
	Liquefaction	Liquefaction of foundation soils or discrete soil stratum results in translation or progressive failure.	There may be little initial movement prior to failure.	A few very large and destructive failures of this type have occurred on high dumps in B.C. See also comments on liquefaction within the dump.	Generally difficult. Depends on type of failure. Tripod monitors may be useless. Detection with other instrumentation depends on character of movement and triggering event.	Borehole inclinometer (perhaps). Piezometer (perhaps).		
	Toe failure	Progressive failure of toe of dump.	Movement starts at toe and may work back into the dump.	Translation or rotational movement.	Difficult to detect with most monitoring methods except possibly non-specific methods such as Acoustic Emission, videometry or photogrammetry.	Photogrammetry Visual	Acoustic emission Videometry	

Continued...

Table 3-1 Summary of Deformation Modes of Typical High Waste Dumps

Mode	Type of Failure	Description	Characteristics of Movement	Comments	Potential for Detection using Monitoring	Types of Monitoring (Typical)	Unusual or Special Types of Monitoring	Sketch
Failure within Embankment.	Edge Slumping	Shallow failure of oversteepened area at crest of dump.	Rapid movement with little warning or prior movements.	Safety hazard. Does not retrogress.	Visual monitoring on a frequent basis is only safe way. Wireline extensometer may detect some of these failures, but many will have only slight movements before failure.	Visual	Videometry Laser camera	
Continued from last page.	Plane Failure	Translation along a weak zone within the dump.	Depending on thickness or volume, failure may be rapid with little warning.	Safety hazard. Generally due to a specific cause (eg., snow or weak soil).	Small failures may be difficult to detect due to limited movement before failure	Wireline extensometer. Surface settlement. EDM or other survey. Piezometer	Videometry Laser camera Acoustic emission	
	Rotational failure	Failure along a curved or circular surface within the dump.	Usually involves weak non-homogeneous material in the dump.	Movements may be large. Perpendiculars to movement vectors at different locations define center of rotation.	Good	Wireline extensometer Buried extensometer Surface settlement Surface tiltmeter EDM or other survey. Piezometer Sampling	Acoustic emission GPS Videometry Laser camera	
	Liquefaction failure within dump.	Failure on a zone within the dump subject to liquefaction.	Likely more common than previously thought as suggested by most recent research.	Movements may take place on dump prior to liquefaction failure.	Prior movements may be detected but prediction of failure depends on understanding the complex mechanisms involved.	Wireline extensometer Buried extensometer EDM or other survey. Piezometer		
	Flow Failures	Slumped material flows down the dump face in a semi-fluid state.	May overlap with liquefaction failures occurring within the dump material.	Little movement may precede failure which is often initiated by outside events (eg., surface water flow).	Difficult to detect based on internal measurements within the dump.	Piezometer Visual	Videometry	

Note: Visual monitoring forms an integral part of dump monitoring and should be used in conjunction with all of the methods outlined above.

Table 4-2 Summary of Types of Monitoring for Different Types of Failure and Dump Classifications

Classification of Dump (B.C. Design Guidelines)	Movement Measurement Options			Pore Pressure Measurement Options			Options of Other Methods of Measurement			Discussion
	Type	Comments	D/A?	Type	Comment	D/A?	Type	Comment	D/A?	
III Moderate Risk dumps requiring more detailed investigation, design and monitoring. IV High risk dumps requiring major design input and requiring monitoring and instrumentation to confirm design. Instrumentation considerations would be similar to the Class III dumps except that the amount of instrumentation deployed would probably be greater and that there would likely be increased emphasis on data acquisition.	Wireline extensometer.	•Usually required for at least spot monitoring of active dump locations. May be combined with other options below. •See comments above and in report regarding direction of movement vector.	Yes				Acoustic emission monitoring	•AE sensors can be installed beneath the advancing dump face or connected to metal borehole casings. •Under development. In time, amy be good in combination with other methods.	Yes	
	Buried extensometer	Consider for: •Longer term movement records capable of providing total movement. •Substitute for wireline monitoring across cracks or in other areas where the surface monitor interferes with surface activities.	Yes	Open or unsealed standpipe	Recommended against except to check saturation level in waste or to obtain water samples for chemical monitoring.	No	EM monitoring	Experimental at the present time.		
	EDM	Often used. May have visibility and damage problems depending on dump.	Maybe.	Pneumatic piezometer	Recommended for installation in the foundation or in the waste. See text for drilling alternatives and for cautions with respect to use.	Maybe				
	Surface settlement	Consider in conjunction with buried extensometer for monitoring of discrete blocks with steeply inclined movement vectors.	Yes	Electrical piezometer	As above.	Yes				

Table 4-2 Summary of Types of Monitoring for Different Types of Failure and Dump Classifications

Classification of Dump (B.C. Design Guidelines)	Movement Measurement Options			Pore Pressure Measurement Options			Options of Other Methods of Measurement			Discussion
	Type	Comments	D/A?	Type	Comment	D/A?	Type	Comment	D/A?	
Classes III and IV Cont'd	Surface Tiltmeters	Surface plates can be attached to concrete blocks or a concrete beam in critical areas. Relatively inexpensive to set up. Very sensitive to rotation movements.	Yes, for some instruments only.	Multi level piezometer	Recommended for use only in following situations: •Chemical testing required for number of different horizons. •Piezometric measurements required for a number of different horizons. Note that installation requires a straight hole and may require drilling through dump material.	No or Yes depending on system.				
	Borehole tiltmeters	Requires drilling holes into dump material. Suitable only for low dumps not undergoing large amounts of settlement or movement. Very sensitive to shear type movements (eg., resulting from weak foundation conditions).	No with exceptions.							
	Shear zone indicator	Requires drilling hole into dump. Suitability similar to borehole tiltmeter, but less expensive and provides less information. Not recommended and not further discussed.	Yes.							
	Fibre optics indicator	Requires drilling a hole into the dump. Overall capabilities similar to the borehole inclinometer with additional advantages and ability to follow larger deflections. Instrument is under development.	Yes							
	Photogrammetry	Problem is that the frequency of readings is low. For large dumps, accuracy falls off due to vertical height.	No							

Table 4-2 Summary of Types of Monitoring for Different Types of Failure and Dump Classifications

Classification of Dump (B.C. Design Guidelines)	Movement Measurement Options			Pore Pressure Measurement Options			Options of Other Methods of Measurement			Discussion
	Type	Comments	D/A?	Type	Comment	D/A?	Type	Comment	D/A?	
Classes III and IV Cont'd	Surface Tiltmeters	Surface plates can be attached to concrete blocks or a concrete beam in critical areas. Relatively inexpensive to set up. Very sensitive to rotation movements.	Yes, for some instruments only.	Multi level piezometer	Recommended for use only in following situations: •Chemical testing required for number of different horizons. •Piezometric measurements required for a number of different horizons. Note that installation requires a straight hole and may require drilling through dump material.	No or Yes depending on system.				
	Borehole tiltmeters	Requires drilling holes into dump material. Suitable only for low dumps not undergoing large amounts of settlement or movement. Very sensitive to shear type movements (eg., resulting from weak foundation conditions).	No with exceptions.							
	Shear zone indicator	Requires drilling hole into dump. Suitability similar to borehole tiltmeter, but less expensive and provides less information. Not recommended and not further discussed.	Yes.							
	Fibre optics indicator	Requires drilling a hole into the dump. Overall capabilities similar to the borehole inclinometer with additional advantages and ability to follow larger deflections. Instrument is under development.	Yes							
	Photogrammetry	Problem is that the frequency of readings is low. For large dumps, accuracy falls off due to vertical height.	No							

Table 4-2 Summary of Types of Monitoring for Different Types of Failure and Dump Classifications

Classification of Dump (B.C. Design Guidelines)	Movement Measurement Options			Pore Pressure Measurement Options			Options of Other Methods of Measurement			Discussion
	Type	Comments	D/A?	Type	Comment	D/A?	Type	Comment	D/A?	
Types III and IV Cont'd	Videometry	Under development. Capability remains to be tested. May be favourable.	Yes, Potentially							
	GPS	Not considered economical at present time, but may be in the future. With the use of reference stations can provide accuracy to ±5 mm. Technology to watch in the future.	Yes							

D/A = Data Acquisition

Table 4-3 Summary of Instrumentation Available for Dump Monitoring

Classification	Name/Type *Data Acquisition?*	Principle	Advantages/Disadvantages	Typical Accuracy	Direction of Maximum Sensitivity	Present Use (All instruments listed have potential use)	Comment
Instruments installed at crest	Wireline extensometer (Tripod monitor or Mechanical Crest Monitor) *Yes*	Temporary wire extensometer supported by simple tripod(s) or post(s) with one end of wire anchored on slope of dump. Other end of wire runs over a pulley and is provided with a readout scale. May be combined with remote readout capability or data recording. Can also be placed with the anchor back from the crest to monitor a crack.	•Simple to erect or to relocate. •Low cost. •Subject to interference from activity and weather. •Typically only part of the movement record of the dump is obtained, since the monitors are usually frequently relocated. •Best for movements involving lateral spreading of the crest. Less or not sensitive to dropping movements at the crest, particularly if the anchor at the end of the cable is improperly located.	2 to 5 mm. Subject to accidents and weather. Note that instrument is insensitive to certain movement vector directions.	Parallel to local direction of wire. See Section 5.2.1.	Usually used.	•Primary method of monitoring the majority of dumps in B.C. and is expected to continue in active use. •Better recognition of the potential problems is required. These problems include extreme variability in sensitivity to different dump failure modes and different locations of movement relative to the locations of the stands. •Should be combined with other systems for critical situations. •See further discussion in report.
	Buried extensometer *Yes*	Replacement of tripod monitor with buried extensometer.	•More expensive than tripod monitor. •Less subject to weather and disturbance by dump activities. •Crest end difficult to anchor below crest of dump and thus less sensitive to down-drop movements than tripod monitor, however, is also more accurate which may overcome part of this problem.	Up to a fraction of a mm.	Horizontal movements or movements parallel to extensometer.	Occasionally used.	•This technology is generally used for monitoring of slopes. Could be applied to dumps with the advantages and disadvantages noted. Worth consideration in correct circumstances, particularly where the tripod monitor results in disruption of activities on the dump surface. •Should be combined with monitoring of vertical displacement. •Attention to potential jamming problem required.
	Settlement gauges *Yes, some.*	Variety of technologies to monitor settlement of the dump crest. Technologies include surveying, tube type monitors and monitors for discrete points.	•Measures vertical movement only. •Cost varies among different systems. •Some systems are capable of remote monitoring.	As good as a few mm depending on system.	Vertical movement.	Occasionally used.	•Useful addition to wireline and buried extensometer monitoring due to increase in vertical sensitivity which may be a large component of some dump failure modes. •Variety of technologies available.
	Electronic Distance Measuring (EDM) *Yes, some*	EDM combined with 1 sec theodolite to give total movement vector of reflecting prism.	•Widely used for pits. •Use on dumps depends on sight lines and prism life. •Common units in mines at present do not allow data acquisition and are labor intensive.	•Few mm provided that good equipment and statistical methods of data reduction are employed.	Full movement vector.	Occasionally used.	•Recommended for use since it provides the total movement vector. •Note that automated systems are becoming available.
Continued...	Global Positioning System (GPS) *Yes*	Location of sensors on the surface determined from signal travel time from dedicated satellites. Can use differential GPS using master reference stations and slave stations to increase accuracy.	•Under development, has been deployed on some US dams. •Promising system for the future to measure total movement vector. •Cost is dropping rapidly.	5 mm in US and Canadian systems presently deployed.	Full movement vector.	Under development.	•Technology to check in the future.

Table 4-3 Summary of Instrumentation Available for Dump Monitoring

Classification	Name/Type *Data Acquisition?*	Principle	Advantages/Disadvantages	Typical Accuracy	Direction of Maximum Sensitivity	Present Use (All instruments listed have potential use)	Comment
Continued from last page.	Surface tiltmeter *Yes, some*	Typical system measures change in tilt of surface at discrete points. Can be either permanently installed instruments or plates which are read with a portable instrument.	•Measures tilt (rotation) only. •Cost varies from low to moderately high depending on system. •Some systems are capable of remote monitoring.	Down to a few seconds of arc depending on system.	Rotation only.	Occasionally used.	•Should only be considered as an accurate and appropriate means to check for failure modes which result in rotation of the dump surface. •For failure modes in which it is applicable, it is highly sensitive and relatively inexpensive. •In most cases, has more general application to rock failure modes than to dumps. •Note that there are two different types of instruments shown in the data sheets.
Instruments installed within dump	Fixed tiltmeter (downhole). *Yes, some.*	Similar to the Slope Indicator type system (TM) but uses fixed downhole instrument which is usually recoverable under some circumstances. Another technology using electrolytic sensors is also available. A technology using optical fibers (lightguide) is also being developed (see data sheets).	•Cost per point is usually high. •Capable of remote read-out or connection to data acquisition system. •Very sensitive to shear type movements near to the location of the instrument but in dumps movement may become too large for instrument to tolerate long before failure occurs. •Requires drill hole.	Down to a few seconds of arc, equivalent to a few mm shear.	Shear on borehole wall.	Not used.	•Not generally applicable to dump monitoring except possibly to foundation liquefaction problems or to research type monitoring.
	Tiltmeter Casing using probe. Lightguide system. *Yes, some.*	Special casing grouted into borehole. Angle of casing from vertical is read with a probe which is lowered into the hole (casing is always read coming up). Another technology using electrolytic sensors is also available. A technology using optical fibers (lightguide) is also being developed. Both technologies would be less sensitive to borehole disturbance than a conventional casing.	•Standard method of monitoring slide shear for soil and rock slopes. •High sensitivity, but total movement of dump could become too high for casing long before actual failure occurs. •Requires a drill hole into the dump. •May best be limited to cases where total deformation is expected to be small, such as foundation liquefaction.	Displacements of 1 to 2 mm may be reliably detected anywhere along casing. Note that correct interpretation methods must be employed.	As above.	Not used.	Recommended only for special applications where the extreme sensitivity is required and where the total deflection of the dump will not become too large for the instrument.
	•Inverted Pendulum •Downhole survey *Yes, some.*	Both methods require a drill hole in the dump. Total range of the instrument depends on the borehole diameter.	•Generally not suitable for dump monitoring due to size of hole required and to good possibility that movement would exceed total movement range. Also difficult to drill the required vertical hole.	1 to 2 mm		Not used.	Not recommended for most applications. Technology is not further discussed in this report.
Continued...	Stress cell *Yes*	Two different technologies are available; one uses a cell which is grouted into a borehole; the other uses a flatjack type cell which is buried.	•Most suited to research type applications requiring knowledge of stress conditions in waste dumps. •Also very useful for correlation of total stress conditions to pore pressure generation in the foundation.	Few psi.	Stress perpendicular to plane of cell.	Occasionally used.	•Recommended for research applications or application to critical situations where knowledge of internal stress conditions in the dump are required. •Could be considered in conjunction with piezometers for determination of pore pressure generation from loading.

Table 4-3 Summary of Instrumentation Available for Dump Monitoring

Classification	Name/Type *Data Acquisition?*	Principle	Advantages/Disadvantages	Typical Accuracy	Direction of Maximum Sensitivity	Present Use (All instruments listed have potential use)	Comment
Continued from last page.	Accelerometer *Yes*	Measures acceleration or vibration type movement.	•Use generally restricted to seismic or blast monitoring applications. Can be combined with data acquisition system. •Component of Acoustic Emission system.	N/A	Vibration	Occasionally used (blast monitoring).	Recommended where seismic or blast monitoring may be required.
	Standpipe Piezometer *Yes, with additions.*	Measures water pressure by the rise of water into a pipe.	•Low sensitivity and low response time. •Allows samples of the formation water to be taken for chemical analysis purposes. •Allows infiltration tests for permeability.	Varies. May be highly misleading in moderate to low permeability materials ($<10^{-3}$ cm/sec).	N/A	Occasionally used.	Not generally recommended except for use in sand or gravel or in highly permeable dump materials with relatively static water tables.
	Transducer Piezometer *Yes.*	Measures water pressure at a point using a transducer (typically either electrical or air pressure). May be buried, installed in hole through the dump or installed in directional or slant hole into foundation.	•Measurement of pore pressure which is provides information relating to stability of dump. •Cost is mostly related to installation. •Some types of installation require hole.	Few psi to fraction of 1 psi depending on technology.	N/A	Occasionally used.	Recommended for use on the majority of dumps. At present is infrequently used.
	Multiple port type Piezometer *Yes*	Measures water pressure at multiple locations within a borehole. Borehole considerations as above.	•Pore pressure considerations as above. •Requires hole, possibly in dump.	As above.	N/A	Infrequently used.	Should be used only where highly detailed knowledge of complex water conditions is required or where samples or other tests are required from several horizons.
	Downhole settlement gauges *Yes, some.*	Number of technologies are available including measurement of casing shortening and use of single or double fluid type gauges.	•Requires hole. •Provides internal movement of dump in vertical direction.		Vertical	Not used.	Not further discussed in this report since the instrument would likely be destroyed by dump movement in any situation where it was desirable to measure settlement within the dump. Note that the technology for measuring settlement at the base of the dump is discussed in the report.
Surveying	EDM	Electronic Distance Measuring.			XYZ	Frequently used.	See discussion above.
	GPS	Global Positioning System.			XYZ	Not presently used.	See discussion above.
	Level surveys *No*	Conventional level survey.			Vertical.	Used.	Conventional surveying of the crest of the dump. Could be combined with the extensometers provide vertical movement of the stands or other locations.
Continued...	Photogrammetry *No*	Stereoscopic measurement on vertical or oblique photo pairs.	•Not well suited to continuous monitoring. •Orthophoto technology may be useful.	Few inches to few feet depending on scale of dump and location.	XYZ	Occasionally used.	

Table 4-3 Summary of Instrumentation Available for Dump Monitoring

Classification	Name/Type *Data Acquisition?*	Principle	Advantages/Disadvantages	Typical Accuracy	Direction of Maximum Sensitivity	Present Use (All instruments listed have potential use)	Comment
Continued from last page.	Videometry *Yes*	Computerized calculation of XYZ coordinates of locations on face or crest of dump from images from video cameras.	•Promising technology under development. •Can provide complete movement field. •Not functional under poor visibility. •Accuracy still to be proven.		XYZ	Not used.	Research ongoing at the Univ. of Victoria, advanced robotics group. There is another similar technology in the laser camera.
	Laser camera *No*	Similar to the videometry device, except the laser camera substitutes a laser for one camera and locates the laser reflection on the surface of the dump.	•May not have sufficient range.		Both	Not used.	Technology under development.
Other	Acoustic emission	Monitoring frequency and duration of microseismic events caused by particle breakdown within the dump. The data may be used to locate movement zones and to approximately predict failures.	•Very simple principles of operation. •Suited to remote monitoring and early warning systems. •Geophones and other instruments are at dump surface. Wave guides may be required to monitor deep emissions within the dump. •Instrumentation may be relatively inexpensive depending on degree of sophistication.	Provides qualitative rather than specific information. Some systems provide an approximate location of the moving zone.	N/A	Not used.	•Has been successfully used in the past to predict failures and zones of failure, typically within hard rock materials. •Further development underway by Schlumberger (1991)
	EM emission	Monitoring the frequency and magnitude of electromagnetic emission caused by fracturing and change in stress of rock particles in a failure zone in the dump.	•May be insensitive to dump movement (has not been tried).		N/A	Not used.	•Has been successfully used to predict earthquakes and is being tried on a preliminary scale to examine ground movement in mines. •Still in early development phase. •Worth watching, but too early to predict whether this technology is applicable to dump monitoring.

Table 4-2 Summary of Types of Monitoring for Different Types of Failure and Dump Classifications

Classification of Dump (B.C. Design Guidelines)	Movement Measurement Options			Pore Pressure Measurement Options			Options of Other Methods of Measurement			Discussion
	Type	Comments	D/A?	Type	Comment	D/A?	Type	Comment	D/A?	
I Typically small low dumps with negligible risk.										Visual monitoring only.
II Low risk dumps with limited design uncertainties and limited construction difficulty.	Wireline extensometer	•Movement rate data would normally be adequate. •See comments in report concerning problems with direction of movement vector which can lead to misinterpretation of readings.	Yes, with modification	Unsealed standpipe	Use discouraged as discussed in text except for homogeneous formations of relatively high permeability.	No				Usually monitoring of Type II dumps would be confined to visual and wireline extensometer monitoring, possibly combined with EDM monitoring unless specific problems develop or are suspected.
	Buried extensometer	•Only required to ease interference with truck movement from wireline extensometer at crest. •Total movement would not normally be a concern.	Yes	Pneumatic piezometer	Usually only required if there are specific design reasons related to foundation or dump material properties.	Yes, but complicated.				
	EDM or other survey methods.	•Could be considered using a simple layout.	Maybe	Electric piezometer	As above.	Yes				
	Photogrammetry	•Could be considered, but the frequency of reading is usually a problem.								

Table 4-4 Summary of Drilling Technologies Relative to Large Dumps

Type of Drill	Manufacturer or Supplier	Technology	Advantages and Disadvantages	Comment	Recommended?
Rotary	Numerous	Conventional air, water or foam rotary.	•Casing the hole is a problem. •Loss of circulation may result in the drill pipe or casing becoming stuck.	•Has been applied but is risky and may not be successful. •Typically very expensive. •Not recommended.	No
Becker	SDS, Vancouver Western Caissons, Vancouver Others	Small pile hammer drives casing with center air return.	•Ideally suited for drilling of gravelly material. •Drilling of strong blocks in coarse material is difficult to impossible. •Installation of instrumentation through the casing is difficult since this is usually withdrawn.	•Has been used several times for drilling shallow holes but not generally recommended.	No
Odex	Dwyidag, Vancouver Kani Foundations, Vancouver Others	Eccentric bit expands or contracts allowing the casing to follow the bit and the bit to be withdrawn through the casing. Rotary-hammer technology similar to airtrack.	•In large sizes could probably do the work. Depth up to 200 m with telescoping casing. •Has reportedly been used to drill through dumps for purposes of acid drainage control (Taylor, RST Technical, 1991).	•Promising technology worthy of consideration although the bit construction may not be sufficiently robust for routine work.	Maybe
ODS eccentric drill	Bulroc (UK), Drill Systems, agent in Calgary	Eccentric button bit produces hole larger than the casing. Bit fits to conventional or top hammer drills.	•123 to 278 mm diameter holes. •Proven in loose rock materials. •Simple and robust.	•Recommended for consideration.	Yes
Modified Pneumatic Rotary (Schram)	Sargent Hauskins and Beckwith, Phoenix (through HBT)	Conventional down-the-hole hammer with simultaneous advance of casing. Under reamer is used for very hard materials to allow casing advance.	•Proven technology in dump materials to 60 m depth. Deeper holes require additional air beyond that on the rig. •Large casing hammer required for holes in excess of ±100 m.	•Good prospect for general use in dump drilling. •Limited availability of rigs in North America.	Yes
Large pneumatic rotary	Several	Water well drill technology using large air rotary drill and set casing.		Potential for doing work depends on depth and conditions.	Maybe
Krupp hydraulic rotary	Krupp Kani Foundations, Vancouver	High torque machine drills casing fitted with crown drill bit. Central cutter bit drills simultaneously and can be withdrawn leaving casing in hole. Alternative is to insert low cost casing into drill casing and withdraw the drill casing.	•Robust proven method for drilling in waste dumps (Island Copper). •Drill machine is expensive. •System is expensive if drill casing remains in hole with crown bit.	•Recommended for consideration.	Yes
Barber Rig	Barber Industries, Calgary Owens Drilling, Cranbrook	Dual rotary utilizing a lower table to rotate and drive casing with a carbide studded shoe which cuts through the boulders. A top rotary head simultaneously handles a down-the-hole casing hammer or tricone bit inside or ahead of the casing crown bit.	•Proven technology in waste dumps and placer deposits to ±300 m depth. •Drills are custom built and expensive. •System is expensive if casing remains in hole with crown bit.		Yes
Navi-Drill	Boyles Bros.	Directional drill from beside or below the dump to allow instrumentation to be set into the foundation of the dump without having to drill any substantial distance through the dump material.	•Proven technology now starting to be used in exploration. •Access to a suitable site may not be possible on all dumps.	•Technology suitable for use where geometry and instrumentation requirements allow. •Likely to be expensive.	Yes

Continued...

Table 4-4 Summary of Drilling Technologies Relative to Large Dumps

Type of Drill	Manufacturer or Supplier	Technology	Advantages and Disadvantages	Comment	Recommended?
Rotary	Numerous	Conventional air, water or foam rotary.	•Casing the hole is a problem. •Loss of circulation may result in the drill pipe or casing becoming stuck.	•Has been applied but is risky and may not be successful. •Typically very expensive. •Not recommended.	No
Reverse circulation Continued from last page.		Double wall drill tube with center return. Can be fitted with down-the-hole percussion bit to advance the hole through hard materials.	•Installation of separate casing is difficult or not possible. •Installation of instruments through the double wall casing is difficult with a high probability of loss of leads.	Not generally recommended for installation of instruments in dumps. Does provide a means for sampling materials in dump or foundation (disturbed samples only).	NO

Table 4-5 Summary of Representative Data Acquisition Technology

System Supplier or Manufacturer	Type of System or Model	Input Channels (numbers)				Output	Other	Comments	Advantages	Disadvantages
		Analog	Counter Up	Counter U/Down	Other					
Synergetics, Boulder, CO	Hydrological Sensor Interface Module	8, 0-5 VDC	1	1		4 digital output lines, 0-5, 0-7.5 or 0-12 VDC. Can output via ARGOS, GEOS, telephone and radio.		Capable of interfacing with a wide variety of inputs and with Synergetics communications modules and modems.	•RTU is comprised of various modules and can be configured to user needs and cost. •Communication by GOES and ARGOS satellite, radio (UHF/VHF) and telephone. •Good terminal error codes for trouble shooting field problems.	•Difficult to program RTU. •Laptop computer is used for field program which is a problem in severe winter conditions. •Company has had some staff turnover.
HANDAR, Sunnyvale, CA	540A-1, 550A, 560A, 570A	Range	Range	Range		Capable of using all discussed output methods with additional and appropriate modules.	•Capable of remote programming, math algorithms etc. •Operation to -40°C is an option.	Primarily designed for meteorological input but likely could be adapted to other types of measurement.	•High quality state-of-the-art equipment. •GOES, VHF/UHF, telephone/modem. •User friendly. •expandable interface cards for memory or sensors. •good user support.	•Relatively expensive. •Unable to communicate with ARGOS. •Limited error codes and program set information for trouble shooting in the field.
Campbell Scientific, Logan, Utah	AM32 Relay Scanner	8 - 16 5 MV to 5 VDC	2 to 4			5 V output		Used mainly as a data logger.	•Variety of input voltages without signal preconditioning.	•Programs are difficult to write. •Requires additional software and hardware for satellite and meteor burst communications.
Geokon, Lebanon, NH	Micro-10 Data Logger	6 single 12 double ended		2		Capable of using GOES satellite or modem.	Based on the Campbell CR10 MCU but adapted for geotechnical use.	Manufactured by a geotechnical instrument supplier and well adapted for reading geotechnical sensors.	•See comments.	
Sierra Misco, Victoria, B.C.	Model 5096 Real Time Data Transmitter	7 0-5 VDC	2	2	4 digital 8 status	•Optional radio VHF/UHF output. •Optional microwave interface.			•Leading edge of meteor burst technology, has own ground station. •Upgrade possible to use GOES and ARGOS. •Local company with software data logging control modules. •Cost effective for the right applications.	•Less flexible than some alternatives.

Continued....

Table 4-5 Summary of Representative Data Acquisition Technology

System Supplier or Manufacturer	Type of System or Model	Input Channels (numbers)				Output	Other	Comments	Advantages	Disadvantages
		Analog	Counter Up	Counter U/Down	Other					
Valcom Ltd., Guelph, Ontario						•GOES, ARGOS •Radio UHF/VHF			•Very cost effective. •User friendly, easy to program. •Very reliable.	•Less flexible than some alternatives. •Data output not in engineering units. •Limited error codes for field trouble shooting.
Geomation Inc., Golden CO (Vancouver supplier is Max Morton and Associates)	System 2300 (Numerous related components)	wide range.				•Radio UHF/VHF •Telephone dial up modem •RS 232	Can be configured as a wide range of different hardware or radio linked networks with remote MCU's (Measurement Control Units) which interface with gateway and network monitor stations.	Wide range of user-configurable modules. Several applications in B.C. for civil engineering monitoring applications.	•Wide range of input modules, some of which are optimized for measurement of geotechnical parameters such as pneumatic piezometers. •Wide temperature range. •Low power requirements. •Extremely flexible in terms of measurement capabilities.	
Doric Dist by: Intertechnology Don Mills, Ont.	Digitrend 245	20/FEM module				•Local printer. •2 RS 232 ports.	•FEM (Front End Modules) communicate to mainframe via 4 wire digital cable (Max 1 mile). •Math modules built in.		•Can be configured to suit a variety of needs.	•Appears to be optimized for thermocouple use. •Limited communication alternatives available from vendor. •Cable links to FEM's are a disadvantage.
RST Instruments Coquitlam, B.C.	Data Trapper Data Logger	8 0-100 Mv 0-2.5 or 0-5 V	1		7 on/off	Built in modem.	•On version fits down a borehole. •Rugged and battery powered.	•Simple unit. •Configured for a different market than some of the more complex units on this table.	•One point relatively simple system. •Battery powered, rugged unit. •Designed for geotechnical measurements. •Downloads to popular PC software file formats.	
Terra Technology Corp, Redmond, WA	Geotechnical Data Acquisition System Model PDL-264	8 "strain gauge type"				1200 baud modem		Not suitable for all types of instrumentation. Modem is slow.		

Notes: 1) There are many more data loggers available than can be shown in the above table.

2) Many of the comments on satellite capable equipment were based on information supplied by Via-Sat under contract to HBT.